ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

COLLEGE OF ARCHITECTURE AND CIVIL ENGINEERING

IMPACT OF EXPANDABLE SOIL ON FOUNDATION OF BUILDING STRUCTURES:

THE CASE OF CONDOMINIUM HOUSES IN ADDIS ABABA

M.Sc. Thesis

By

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June, 2017

Addis Ababa

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A thesis submitted to the college of architecture and civil engineering of Addis Ababa Science and Technology University in partial fulfillment of the requirements for the Degree of Masters of Science in Geotechnical Engineering

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ABBREVIATIONS

AASHTO	American Association of State Highway Transport Officials
ASTM	American Society for testing materials
B	Width of foundation
Df	Depth of foundation
EBCS	Ethiopian Building Code Standards
LL	liquid limit
Pl	Plasticity Index
PL	Plastic limit
Sample No.	Sample number
SPSS version	Statistical package for social sciences
USCS	Unified soil classification system
ERA	Ethiopian Roads Authority

ABSTRACT

This study was carried out in Addis Ababa where expansive soils are highly abundant. The aim of the study is to assess the general impact of expandable soil in Addis Ababa taking a case study in the newly constructed condominium houses. The choice of condominium houses are on the basis of being constructed on expansive soils. Accordingly, questionnaire survey, field investigation, soil samplings and subsequent laboratory testing were conducted. Questionnaire survey includes a total of 84 professionals were randomly selected from the list of the employees of Bole Arabsa and Koyefeche; and 90 owners from 45 block of condominium house were randomly selected from Jemo No.1, Yeka No.1 and Bole Ayatchefe. During field investigation and observations, 249 blocks were considered. In characterizing the soils engineering properties, 18 soil samples from Koyefeche and Bole Arabsa were collected and tested for free swell, water content, linear shrinkage and Atterberg limit (liquid limit, plastic limit and plasticity Index). Results showed that cracks found in many condominium houses whose pattern are mostly similar and ranging from slight to moderate crack damage. The damage ranges from dormant to moderate in 24.89% of blocks. It is observed that 41.36% of blocks have been cracked of masonry wall in different segments. It is also noted that 46.58% of blocks demonstrate settlement of masonry wall below the grade beam; 53.41% of blocks showed problem of suspending grade beam; and 18.07% of blocks column alignment problem due to suspension of grade beam. It is also found 77.8% of the soils test result showed high plasticity index. To support that most of the soil have high swelling potential.

Keywords: Expandable soil, newly foundations, condominium, respondents, plasticity Index

CHAPTER 1: INTRODUCTION

1.1 Background

Ethiopia has been witnessing a dramatic increase in urbanization associated with increased population. This increase accompanied by a strong need for the infrastructure development and associated civil works. Adequate knowledge of the sub-surface geology and soils on foundation is therefore very important for the safety and economic design of engineering structures.

Soil is an essential component in civil engineering infrastructures development. It often controls the design and cost of construction projects, predominantly light weight and shallowly founded structures. Some soils, such as expansive soils, are known to be problematic and require particular attention.

Expansive soil is a term generally applied to any soil that has a potential for shrinking or swelling under changing moisture conditions. Subsequent swelling and shrinkage of this soils due to change in moisture cause damages to civil engineering structures, particularly light buildings and pavements (John and Debora, 1992). Swelling and shrinkage potential of expansive soils depend on several factors, such as type and amount of soil constituent of clay minerals; initial moisture content, and the soil water chemistry contained within voids; initial density or void ratios; grain size structure and soil fabric; the state of stress, the state of stress, which is applied stress level and stress history (Chen, 1988; Skempton, 1984; Thomas et al., 2000).The conditions and processes which determine the clay mineralogy include composition of the parent material and degree of weathering to which the materials are subjected. Active clay minerals are prominently sensitive to moisture content fluctuation.

The overall geotechnical characteristics such as volume, strength and stability of soils containing these minerals show extreme variation upon wetting and drying (Morin and Parry, 1971). Three clay mineral species, smectite (montimorillonite, nontronite), illite, and kaolinite (in decreasing order of activity) (Skempton, 1984) are established to be fundamental indicators of soil swelling and shrinkage potential (Thomas et al., 2000). These clay mineral species are structurally and compositionally different and exhibit distinctive physicochemical characteristics (Yong and Warkentin, 1975).

According to AlemayehuTeferra and Solomon Yohannes (1986) the black and grey soils found in the eastern and southern part of Addis Ababa are highly expansive and there is no distinction between the heaving characteristics of the grey and black soils. The clay content of the soil is found to be as high as 80% and the amount of montimorillonite for Addis Ababa expansive soil is 70-80%. These soils have the ability to hold significant amount of water that affects the shear strength, as well as, shrinkage and swelling characteristics (Luelseged Ayalew, 1990).

Problem soils are considered as one of the natural geo-hazards that affect substantial danger to human life, property, infrastructure and environment. Bell (1999) defined problem soils also as natural geo-hazards that are due to detrimental geotechnical properties of soils. Expansive soils fall into these problem soil geo-hazard category. According to Jones and Holtz (1973) and Bell (1999), global damage to infrastructure and associated remediation costs are often of far reaching economic consequences. Recent researches in assessing the failures caused on structures built on expansive soils showed that more than 60% of the structures are damaged due to causes associated with expansive soils (Sisay Alemayehu, 2004). Thus, the presence of expansive soils in construction sites such as building foundation is problematic, unless proper care is taken during the planning, location, design and construction of such activities.

In light of the aforementioned discussion, this study will be conducted in Addis Ababa, particularly in AkakiKality, Bole, Nifas Silk and Yeka sub-cities where the newly constructed condominiums are located ,with the aim of defining genesis, physical properties, and impact review of expansive soils for shallow founded building structures and forwarding appropriate and relevant recommendation.

1.2 Origin and Distribution of Expansive Soils

Expansive soils are found in different parts of the world, apart from Ethiopia, such soils are commonly found in USA, Australia, India, China, Sudan, South Africa, Niger, Tanzania (Chen, 1988, Morin, 1971) etc. The behavior of expansive soils varies from place to place depending upon the type of parent material, climate and topography.

Most of the Ethiopian plateau and part of Somalian plateau are covered with tropical clays, predominantly black cotton and other clayey soils (Morin and Parry, 1971).

Such soils formed over Tertiary to Recent basaltic rocks which cover the central, western, north-western, south-western and some parts of southern and eastern Ethiopia they often occur in flat and gently sloping landscapes such as on the highland plateau, low land flood plains and valley floors (Morin and Parry, 1971).

According to Alemayehu Teferra and Solomon Yohannes (1986) the black and grey expansive soils found in the eastern including study area and southern part of Addis Ababa are highly expansive and there is no distinction between the heaving characteristics of the grey and black soils.

1.3 Statement of the Problem

In recent years, Addis Ababa has witnessed a nenormous infrastructure development and also is a place where widespread expansive soils are abundant. As a result, it becomes important to understand and consider expansive nature of soil properties, which is responsible for a possible damage of properties, human life and related economic loses; and it is also observed in the Addis Ababa that many condominium houses, transport routes and buildings are founded on these soils. Though detail assessment is needed, some related impact of expansive soils like cracks, grade beam failures and differential settlement are noted in some condominium house.

The study area was covered with expansive soils and construction is booming with residential, condominium and commercial buildings; however, proper assessment of expansive soil is barely considered pertaining to the newly constructed condominium buildings.

In the present study, an attempt was made to characterize the expansive soil and define their impact on the selected newly constructed condominium houses and previously services in advance too. All relevant factors affecting soil behavior and other ground conditions would be considered so that a clear understanding on engineering behavior of expansive soils could be assessed.

1.4 Objectives of the Research

1.4.1 General Objective

The general objective of this study is to assess the impact of expandable soil in Addis Ababa taking a case study in the newly foundations and constructed condominium houses.

1.4.2 Specific Objectives

To meet the general objectives, the following specific objectives were designed:

- to identify, define and characterize expansive soils in the study area
- to define index and engineering properties of expansive soils
- to assess the impact of expansive soil in the newly foundations and constructed condominium houses
- to record the extent and cause of failure on the newly foundation and damages on constructed condominium houses

1.5 Significance of the Research

The results and findings are expected to contribute towards safe and economic design of foundation in the study area. It will also provide helpful information for land use planning, particularly for buildings, and other civil engineering construction activities; in addition, it may be applied to similar area where expansive soils are present.

CHAPTER 2: LITERATURE REVIEW

2.1 Expansive Soils in General

Expansive soil is a term used for soils which exhibit moderate to high plasticity, low to moderate strength and high swell and shrinkage characteristics (Holtz and Gibbs, 1956).

Expansive clay soils covered large parts of Ethiopia and Sudan and smaller parts of the areas in Tanzania, Kenya, Uganda, Malawi and Zambia. The associated volcanic rocks are the main source for the black clays formation in Ethiopia, Kenya and Sudan (Lyone Associates, 1971).

Most of the Ethiopian plateau and part of Somalian plateau are covered with tropical black clays (Morin and Parry, 1971). Expansive soils, predominantly black cotton and other clayey soils occur in various parts of Ethiopia. In the central, western, north-western, south-western and some parts of southern and eastern Ethiopia they often occur covering an extensive area. Such soils commonly occur in flat and gently sloping landscapes such as on the highland plateau, low land flood plains and valley floors (Morin and Parry, 1971). These soils are notorious for exhibiting harmful geotechnical characteristics and causing costly hazards particularly in the construction sector (Morin and parry, 1971; Netterberg, 2001).

Genesis

The parent materials that can be associated with expansive soils are classified into two groups. The first comprises the basic igneous rocks and the second group comprises the sedimentary rocks that contain montmorillonite as a constituent. The basic igneous rocks are comparatively low in silica, generally about 45% to 52% rocks those are rich in metallic base such as the pyroxenes, amphiboles and olivine fall within this category such rocks include the gabbros, basalts and volcanic glass (Gillott, 1968; Grim, 1953). The sedimentary rocks that contain montmorillonite as constituent include shale, clay stone, limestone and marls rich in magnesium can also weather to clay (Gillott, 1968; Grim, 1953). The volcanic eruptions sent up clouds of ash, which fell on the continents and sea and some of fine grained sediments which accumulated to form these rocks also contain montimorillonite derived from weathering of continental igneous rocks and from ash, which fell on the continental areas as clouds of ash from volcanic eruptions can fall on continents and sea (Gillott, 1968; Grim, 1953).

Weathering

The weathering processes by which clays are formed include physical, chemical and biological processes. Since water is the prime source of weathering, climatic conditions play an important role in the rate and extent of weathering of the parent material. Climate ultimately becomes the most dominant factor in residual soil formation than parent material. The formation of expansive clays or montimorillonite clays is favored by alkaline environment, the absence of leaching. The presence of feromagnesium minerals and the presence of bases, prolonged leaching under tropical conditions favors formation of minerals of the kaolinite group, which are non-expansive (Grim, 1953).

2.2 Mineralogy of Expansive Soils

Expansivity of soils is due to the presence of clay minerals. Clay particles have sizes of 0.002mm or less. However, according to Chen (1988) the grain size alone does not determine clay minerals and he emphasized that the most important property of fine grained soils is their mineralogical composition.

There are two fundamental molecular structures as the basic units of the lattice structure of clay soils. These are the silica tetrahedron and the alumina octahedron. The silica tetrahedron consists of a silicon atom surrounded tetrahedrally by oxygen ions. The alumina octahedron consists of an aluminium atom surrounded octahedrally by six oxygen ions. There are valency imbalances in both units, resulting in net negative charges.

The basic units, therefore, do not exist in isolation but combine to form sheet structures. When each oxygen atom is shared by two tetrahedral, a plate-shaped layer is formed. Similarly, when each aluminium atom is shared by two octahedrons, a sheet is formed. The silica sheets and the aluminium sheets combine to form the basic structural units of the clay particles. Various clay minerals differ in the stacking configuration (Murray, 2007; Craig, 2004).

The tetrahedral sheet (also called silica sheet) retains a net negative charge but the octahedral sheet (gibbsite sheet) is electrically neutral. Silicon and aluminium may be partially replaced by other elements, this being known as isomorphous substitution, resulting in further charge imbalance. The sheet structures are represented symbolically in Figure 2.2(a). Layer structures then form by the bonding of a silica sheet with either one or two gibbsite sheets.

Clay mineral particles consist of stacks of these layers, with different forms of bonding between the layers. The structures of the principal clay minerals are depicted in Figure 2.2 (Craig, 2004).

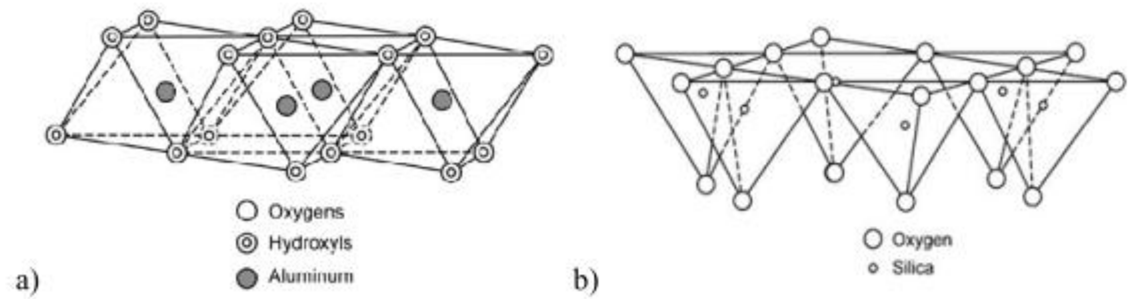

Figure 2.1.Diagrammatic Sketch of a) Octahedral Sheet; b) Tetrahedral Sheet (Murray, 2007)

Differences in soil geotechnical characteristics show dependency on clay mineralogical compositions among different clay mineral varieties such as montimorillonite, illite, and kaolinite (Thomas et al., 2000). These clay mineral species are structurally and compositionally different and exhibit distinctive physicochemical characteristics (Brigatti et al., 2006).

Primary structural unit of montmorillonite is a layer composed of two silica tetrahedral sheets with a central alumina octahedral sheet. Such a structure is referred to as a 2:1 structure. Although the layers are continuous, bonds between layers provided by van der Waals forces and interlayer cations (Brigatti et al., 2006) are exceptionally weak, permitting water molecules to occupy the space between layers (Gillot, 1987). Montimorillonite often occurs in a remarkably small platy film like forms. This clay mineral has a large specific surface area (Ross, 1978) which adds to its high affinity to water molecules (Gillot, 1987).Thus, it is susceptible to considerable swelling upon wetting (Ross, 1978). On the other hand, loss of moisture (drying) causes proportionally substantial volumetric shrinkage (Bowels, 1984).

Illite has a structure where single sheet of alumina octahedrons are sandwiched between single sheets of silica tetrahedrons (Brigatti et al., 2006), which is similar to the smectite clay mineral varieties. Bonding provided by potassium ions is weak, allowing water molecules to be absorbed between layers. Illites expand more than those of kaolonite clay mineral types; but much less than smectite clay mineral varieties (Gillot, 1987). Illite commonly occurs in flaky forms. It has much smaller specific area and affinity to water molecules than montimorillonite (Chen, 1988; Gillot, 1987; Skempton, 1984). Illite often occurs as a mixed smectite-illite (interstratified) variety (Brigatti et al., 2006), exhibiting properties between the two clay minerals including moderate swelling and shrinkage potential (Yong and Warkentin, 1975).

Kaolinite has a basic structural unit consisting of single sheets of silica tetrahedrons bonded with single sheets of alumina octahedrons staking together (Yong and Warkentin, 1975). This structure is referred to as a 1:1 structure. Bonding provided by hydrogen molecule is strong, which minimizes interlayer space for absorption of water molecules. Nelson (2010) described that kaolinite is formed by weathering or hydrothermal alteration of rocks rich in feldspar in low PH condition to favor the leaching out of ions like sodium, potassium, calcium, magnesium and iron. Two varieties, kaolinite and halloysite, of clay minerals are of importance with respect to soil swelling and shrinkage potential (Bell, 2000). The kaolinite variety often occurs as plates. The halloysite variety, which has a single layer of water, weakly adsorbed between its sheets (mainly held on surface particles) usually occur in tabular forms. Kaolinite clay minerals are characterized by a smaller specific surface area than montmorillonitic and illitic clay mineral varieties. As a result, kaolinites exhibit little water affinity and are characterized by minimal expansion rates (Chen, 1988; Thomas et al., 2000). Occurrences of the mixed layer (interstratified) smectite-kaolinite and illite-kaolinite clay minerals are common in soils (Yong and Warkentin, 1975). Soils containing these interstratified clay minerals show a higher expansion and shrinkage potential than the pure kaolinite species (Yong and Warkentin, 1975).

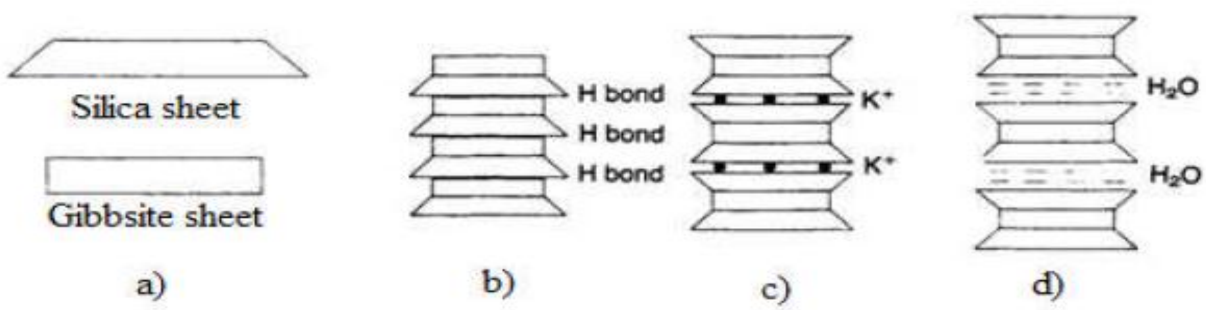

Figure 2.2.Principal Clay Minerals: a) Symbolic Representation of the Sheet Structures; b) Kaolinite; c) Illite and d) Montimorillonite (Craig, 2004)

2.3 Identification of Expansive Soils

A major concern in geotechnical engineering is identification of expansive soils, either in the field or laboratory, and estimation of their swelling magnitudes when subjected to changes in environment so that problems posed by them can be counteracted (Al-Rawas and Goosen, 2006).

2.4 Field Identification

Soils that can exhibit high swelling potential can be identified by field observations, mainly during reconnaissance and preliminary investigation stages (Chen, 1988; Nelson, 1992). During dry seasons, shrinkage cracks are visible on the ground surface with the maximum width of these cracks reaching up to 20 mm or more and they travel deep into the ground (Murthy, 2009). During rainy seasons, these soils become very sticky and very difficult to traverse. Appearance of cracking in the nearby structures is also indicative (Murthy, 2009).

2.5 Laboratory Identification

According to Chen (1988) shrink–swell behavior can be best predicted by examining a combination of physical, chemical, and mineralogical soil properties. To achieve this, many tests and method have been developed. These include mineralogical, direct and indirect identification techniques (Chen, 1988).

The mineralogical identification methods, such as : X-ray diffraction, Differential thermal analysis, Dye absorption, Electron microscope, Base exchange capacity, etc, use the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and change deficiency and surface activity of clay particle (Chen, 1988; Neslson, 1992). These properties are fundamental factors controlling expansive soil behavior. However, they are not suitable for routine testing as they are time consuming, require expensive test equipment and, the results are interpreted by specially trained technicians (Chen, 1988). Fell et al. (2005) described the identification techniques of clay minerals in soils and recommended to apply at least two of them at a time.

Indirect methods involve the use of indirect information from soil index and physical properties and classification schemes to estimate shrink–swell potential (Chen, 1988; Neslson, 1992). These include Index Property Tests, Cation Exchange Capacity (CEC), and Potential Volume

Change (PVC) test. None of the indirect methods should be used independently.Grain Size Analysis, Atterberg Limit and Free Swell tests are some, among the routinely conducted index property tests. Holtz and Gibbs (1956) demonstrated that the liquid limit and plasticity index are useful for determining the swelling characteristics of most of the clays and prepared a chart to assist the identification. Since the LL and swelling of clays both depend on the amount of water clay tries to imbibe, it is not surprising that they are related (Chen, 1988; Ulusay, 2002). While it may be true that high swelling soil will manifest high index property, the converse is not true (Chen, 1988).The direct method provides the actual physical measurement of swelling that the soil undergoes as the moisture content changes. This type of test directly measures the pressure that a swelling soil exerts on any structure resting on it. It is a convenient and more reliable test because it directly tells the likely insitu response of the soil for moisture variations. The test can be done by the use of a conventional one-dimensional Consolidometer which is available in most soil mechanics laboratories (Chen, 1988; Neslson, 1992) .

2.6 Classification of Expansive Soils

Soil classification is an important aspect of laboratory test, which tells the characteristic of the soil under interest. There are a number of classification systems based on identification tests. Among these, the Unified Soil Classification System (USCS) and the American Association of State Highway Transport Officials (AASHTO) method make use the liquid limit and plasticity index of the soil. Geotechnical engineers generally prefer the USCS while the AASHTO classification is common in state and country highway departments (Das, 2011).

2.7 Properties of Expansive Soils

Expansive soils typically exhibit a large amount of volumetric swelling and shrinkage, in response to change in moisture content (Bell, 1999; Jones and Holtz, 1973). This property can detrimentally influence construction, performance and life time, especially of lightweight civil engineering infrastructure. Major problems are volume changes due to cyclic swelling and shrinkage upon wetting and drying, which can lead to differential heave, settlement and creep; decrease in bearing capacity and shearing strength of soils when saturated; and difficult workability conditions (both in saturated and dry state)(Bell, 1999; Jones and Holtz, 1973).

Rao (2007) pointed out the nature and characteristics of the expansive soils. Expansive soils absorb water heavily, swell, become soft and lose strength. These soils are easily compressible when wet and possesses a tendency to heave during wet condition and shrink in volume and develop cracks during dry seasons of the year. These soils are characterized by extreme hardness and cracks when dry.Holland and Rechards (1982) outlined that the seasonal changes in volume of expansive soil is manifested by horizontal and vertical movements. The horizontal movements lead to fissure opening during drying and closing during wetting whereas the vertical movements lead to cyclic changes in soil levels. The authors described that the magnitude of these movements decreases with depth where there is no seasonal moisture changes.

2.8 Mechanics of Swelling

Swelling of expansive soils will take place under change in the environment of the soil (Chen, 1988). Environmental change can consist of pressure release due to excavation, desiccation caused by temperature increase, and volume increase because of the introduction of moisture. There must be a potential gradient, which can cause water migration and a continuous passage through which water transfer can take place (Chen, 1988). The potential gradient in expansive soils can be due to seasonal moisture fluctuation or thermal gradient, which can cause vapor and liquid moisture transfer (Bell, 2000) . Vapor transfer plays an important role in providing the means for the volume increase of expansive soils (Ross, 1978).

2.9 Factors Influencing Swelling of Expansive Soil

Swelling and shrinkage potential of expansive soils depend on several factors, such as type and amount of soil constituent clay minerals; initial moisture content, and the soil water chemistry contained within voids; initial density or void ratio; grain size, structure and soil fabric; the state of stress, which is the applied stress level and stress history (Bell, 2000; Chen, 1988; Nelson and Miller, 1992). The swelling characteristics of soils result in heaving, distortion, cracking and breaking up of pavements, buildings, channels, buried conduits and reservoir linings. Retaining walls with expansive soil backfills may be subjected to very high earth pressures leading to considerable tilting and ultimately failure of the structures. Shrinkage of expansive soils due to prolonged drought can cause very severe settlements, which may be detrimental to structures founded on them. In road pavements, for instance, extensive cracking may occur. Shrinkage cracks increase permeability of an impervious core of swelling clay and this may cause seepage problems in water reservoirs (Chen, 1998).

2.10 Previous Works on Expansive Soils

Researches on the engineering properties of expansive soils in different parts of the world have been done. Some of the researches undertaken are;

Van der Merwe (1964) presented the volumetric changes in the road bed caused by seasonal moisture and volume changes in expansive soils of Zimbabwe. The work focused on defining the properties of soils, which caused deformation so that they can be identified and determined in the field. The work also included formulating road construction and maintenance strategies to counteract the damaging effect of expansive soils.

Barry (1986) presented the influence of trees and shrubs on pavement loss of shape. The paper recommended that, to guard pavement loss of shape, from drying of expansive soils by trees, trees and shrubs should be set back at distance equal to 2 times the mature canopy width of the tress or 1.5 times the mature tree height, whichever is greater, from the edge of pavement.

Netterberg (2001) gave descriptions of a full-scale road experiment on the Pretoria Warm bath freeway in South Africa employing four different countermeasures against damage due to the highly active clay roadbed. The entire four counter measures used, i.e. 1.0m replacement, pre-wetting (by rainfall) alone, pre-wetting and membranes; and a combination of 0.5 m replacement, pre-wetting and membranes have performed satisfactorily.

Chen (1988) provided a summary of the state of-the-art knowledge of expansive soils and practical solutions based upon experiences. Theory, practice and typical case studies are also presented in his study.

The Geological Society (1997) reviewed the nature of different tropical residual soils and gives valuable information on how their peculiarities influence their testing and use in civil engineering. Each type of residual soil has well defined characteristics deriving from the nature of the parent rock and the climate prevailing in recent geological times. Thus, whenever similar climatic and geological conditions occur, the same types of residual soils are evolving, sometimes at different stages of development.

Morin and Parry (1971) presented the occurrences and properties black and red clay soils. They pointed out that the black clay soils are difficult to utilize in construction because they contain a large percentage of expansive clay minerals.

2.10.1 Building constructed on expensive soils and it's Experience in Addis Ababa

Buildings founded on swelling soils often show movements, which appear to be opposite to the dish shaped distortion resulting from consolidation settlement. Since the building acts as an impermeable membrane, there will be a tendency of moisture accumulating underneath the building resulting in maximum heave at the center. For the same vertical deformation at the center of the buildings, hogging (heaving) develops very serious crack patterns compared to sagging (settlement). The type of building damage includes displacements of foundations, heaving of floors, cracking of walls and damage to ceilings, services and sidewalks. (AfewerkSisay, 2004) in Addis Ababa, shows most building constructed on expensive soils with cracks from heave from the underlying soil has foundations made from masonry with tie beams. On the other hand, building with floating foundations and pile, had relatively damages which are smaller in magnitude.

2.11 Engineering issues

Many towns, cities, transport routes, services and buildings are founded on expansive soils. These may be solid (bed rock) geological strata in a weathered or un-weathered condition, or superficial (drift) geological strata such as glacial or alluvial material, also in a weathered or un-weathered condition. These materials constitute a significance hazard to engineering construction in terms of their ability to swell or shrink, usually caused by seasonal changes in moisture content .The structures most affected by expansive soils include the foundations and walls of residential and other low-rise buildings, pipelines, pylons, pavements and shallow services. Frequently, these structures only receive a cursory site investigation, if any; it is usually not until sometime affect construction, which problems may come to light. Damage can occur within a few months of construction, develop slowly over a period of 3-5 years, or remain hidden until something happens that changes the water content of the soil. The structures most susceptible to damage caused by expansive soils are usually lightweight in construction. house, pavements and shallow services are especially vulnerable to damage because they are less able to suppress differential movements than heavier multi-story structures (Cheney, 1986).

2.12 Effect of unfit design on building construction

Some research result showed that; the traditional design criteria of considering bearing capacity prove failure in expansive soils. Some research outcome showed that problems of expansive soils results from a wide range of factors; Shrinkage and swelling of clay soils are resulting from moisture change, Type of the clay size particles, Drainage –rise of ground water or poor surface drainage and Compression of the soil strata resulting from applied load. Other factors include Pressure of the backfill soil, soil softening, weather, vegetation and Amount of aging (Thomas et al., 2000).All these should be considered to come out with the choice of appropriate design criteria for careful selection of the proper type of foundation, type of structure and type of construction materials. With proper knowledge of the above indicatives, the potential for structural damage will be a thing of the past (Chen, F.H, 1998).

In Addis Ababa; many condominium houses, transport routes and building are founded on expansive soils. The clays within these materials may be significant hazard to engineering construction due to their ability to shrink or swell with changes in water content. However; city planners and engineers did not appear to pay attention to the problems associated with expansive soil during site selection and construction of low-rise and low-cost buildings (AfeworkSisay, 2004).

2.12.1 Impact on General Building Stock

Because of differences in building construction, residential structures and one-story commercial structures are more susceptible to damage by expansive soils compared to multi-story buildings. Multi-story buildings are heavier and can generally counter the swelling pressures. The exception is when multi-story buildings are built on wet clay, and may experience damage because shrinkage of the clay if moisture levels are substantially reduced (be evapo transpiration or by evaporation from under heated buildings).Various types of structural damage to buildings include sticking doors; uneven flooring; and cracked foundations, floors, walls, ceilings and windows. Damage to small buildings is greatest when the structure is built on dry clay, such as during drought conditions, followed by rain which swells the soil. Human activities can also influence the moisture of the soils including an increase in moisture from broken or leakage water and sewer lines, watering the landscaping, and surface ponding (Al-Rawas and Goosen, 2006).

Table 2.1.Classification of Visible Damage to Walls

Category of Damage	**Degree of Damage**	**Description of Typical Damage**	**Approximate Crack Width (mm)**
0	Negligible	Hairline crack of less than about 0.1 mm widths are classed as negligible. No actions required.	Up to 0.1
1	Very Slight	Fine cracks which can be easily treated during normal decoration. Damage generally restricted to internal wall finishes, crack rarely visible in external brickwork.	Up to 1
2	Slight	Crack easily filled. Recurrent crack can be masked by suitable linings. Cracks on not necessarily visible Externally, some external reappointing may be required to ensure weather tightness. Doors and Windows may slight and require easing and adjusting.	Up to 5
3	Moderate	Crack which required some opening up and can be patched by a mason. Repointing of external brickwork and Possibly small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired.	5 to 15 (or several of 3mm)
4	Severe	Extensive damage which required breaking-out and replacing sections of walls, especially over doors and windows. Windows and doors frame distorted, floor sloping noticeably. Wall leaning or bulging noticeable, Some loss of bearing in beams. Service pipes disrupted.	15 to 25 But also depend on number of crack

5	Very Severe	Structural damage which requires a major repair job involving partial or complete rebuilding. Beams lose bearing, wall lean badly and require shoring. Windows broken with distortion. Danger of instability	Usually greater than 25 but depends on number of crack

Source: *Defect in Building, 2003*

2.12.2 Geotechnical problems on building construction

Many buildings on lightly loaded slabs or footings, such as residential houses, hotels, and garages have suffered erratic cracking consisting of corner. Down type of construction, upward heaving near the middle of walls, slight rotation of stem walls, horizontal translation outward, and slight rotation of corner about vertical axis,(pop,1997).The predominant movement observed in buildings on expansive soils is one of the upward heave or a dome-shaped heave with the greatest upward movement occurring at the center of the building. The resulting cracking pattern has the appearance of a corner-down distortion. Stresses at the corners are relatively higher than along the rest of the longitudinal footings due to the presence of windows and doors opening over the latter. Therefore it may be expected that the corners of the footings would settle more than the middle (pop, 1997).

2.13 Preconstruction techniques for minimizing damaging

i) Removal of expansive soil and replacement with non-expansive soil

Removal of natural expansive subgrade material and replacement with a non-expansive material is most obvious method of eliminating swell problems. In some cases this approach may be economical if the expansive stratum is thin and replacement materials are available. Unfortunately, this is generally not the case, and the excavation and replacement solution is extended only to a depth which will reduce swelling to a tolerable minimum. Hence the required depth of excavation depends up on the expansivenesses of the soil and the anticipated weight of backfill and structure which counteract the uplift forces of the swelling soil. The selection of the particular non expansive backfill material is critical. (Snethen, D.R, 1975), suggests that replacement soils be impervious as pervious soils may create conditions conductive to the collection of water or the condensation of moisture from the air through hydrogenesis.

ii) Application of surcharge pressure

Loading the expansive soil with pressure greater than the swelling pressure is a method by which swelling can be prevented. However, pavement loads are generally insufficient to prevent expansion, and this method is usually applied in the case of large buildings or structure imposing high loads (John, D and Debora, J 1992).

iii) Preventing access of water to the soil

Since the change in moisture content is the main factor influencing the volume changes of swelling soils, it is obvious that if the soil could be isolated from any moisture changes, volume change could be reduced or minimized. In this perspective, waterproof membranes are becoming an increasingly promising method for limiting access of water and minimizing moisture changes. (Snethen, D.R, 1975)

v) Pre-wetting the soil

Pre-wetting is to allow desiccated swelling soils to reach equilibrium prior to placement of the road way or structure. The most commonly applied method for accelerating swelling by this technique is ponding. (Snethen, D.R, 1975), the questions of how long the material should be ponded and to what depth the moisture should penetrate to be effective are still unknown.

vi) Stabilization by chemical admixtures

Chemical stabilization has been a method for altering the clay structure or clay-water combination to prevent or minimize swelling of expansive clays. Literally hundreds of chemicals or additives have been tried. Lime is the most widely used and effective additive for stabilization of expansive soils. And lime continues to be the most effective and most widely used additive for treating expansive soils. Initially, lime treatment was confined to the upper few inches of subgrade, perhaps primarily to achieve strength benefits and not so much to treat the expansive problem (Snethen, D.R.1975).

vii) Mechanical stabilization

Considerable experimental evidence exists that conditions of compaction have a considerable effect on the swelling characteristics of compacted expansive soils. (Snethen, D.R.1975), the method of compaction also influences swelling characteristics of compacted swelling soils. An expansive soil with a dispersed (deflocculated) structure swells less than one with a flocculated structure for the same water content density.

2.14 Foundation

2.14.1History of foundation engineering practices in Ethiopia

The history of foundation engineering in Ethiopia had not been documented so far. The only reference document to mention is the Ethiopian Standard Code of Practice (ESCP-3) which was established for the first time by the Ministry of Construction in 1983. The code was established as per the statement put in the Definition of Powers and Responsibilities of Ministers Amendment Proclamation No.216 of 1981.

In this regard, the proclamation No.191 of 1980 presumes, particularly in the area of building construction, the issuance of appropriate directives and regulations by the Ministry of Construction against which the performance of construction works, plans and designs carried out by contractors, designers and other professionals can be evaluated (ESCP-3, 1983).In discharge of such responsibilities, the Ministry of Construction issued a series of codes of practice, of which a code of practice for foundations (ESCP-3) was prepared. As stated in the foreword of the Manual, the purpose of the code is to establish a national standard which sets down the minimum requirements of the design and construction of foundations for the normal range of buildings and other engineering infrastructures.

Prior to the 1983, the practice in the design and construction of foundations for buildings and other engineering structures depended on adopting different foreign national codes. In such practice, problems arise not only in the specific values used but also in the approach adopted due to differences in the requirements of the different codes especially with regard to safety and economic considerations(ESCP-3, 1983).According the Manual, the major benefits expected to be gained in complying with the requirements of this code are the harmonization of professional practice and ensuring of appropriate levels of safety and be economical.

Although not stated clearly in the new code of standard, ESPC-3 had been reviewed and modified in 1995 and a new code has been established. The 1995 code is named as the Ethiopian Building Code Standard (EBCS-7). Until now, the EBCS-7 hadn't been reviewed. The author of this thesis believes that neither ESPC-3 nor EBCS-7 contain the relevant requirements for design and construction of foundations as per the country's existing conditions. As a consequence, most organizations engaged in geotechnical investigations are often forced to use additional code or documents for the design and analysis of foundations.

2.14.2 Types of Shallow Foundation

A shallow foundation transmits structural load to the soil at relatively lesser depth. According to Terzaghi (1943) in shallow foundations the depth ‘ Df ’ should not exceed B, the width of the foundation, i.e., $Df/B \leq 1$.shallow foundations in soils are required when the magnitude of loads to be transmitted to the foundation soil is relatively small and the soils at shallow depth posses relatively satisfactory bearing capacity. Besides the foundation soils at shallow depths do demonstrate settlement potential within permissible limits.

2.14.2.1 Strip footing

A strip footing is provided for a load –bearing wall. A strip footing is also provided for a row of columns, which are so closely spaced that their spread footings overlap or nearly touch each other. In such a case, it is economical to provide a strip footing than to provide a number of spread footings in one line. A strip footing is also known as continuous footing. In strip footing or continuous footing the length is much greater than its width (AlemayehuTefera and Solomon Yohannes, 1986).

2.14.2.2 Spread footing

A footing carrying a single column is called a spread footing, since its function is to spread the column load laterally to the soil so that the stress intensity is reduced to a value that the soil can safely carry. These members are sometimes called single or isolated footings. As the term itself indicates spread footing takes up the weight of part of the building and spreads it over a larger area in order to decrease the unit load.

2.14.2.3 Combined footing

A combined footing supports two columns. It is used when the two columns are so close to each other that their individual footings would overlap. A combined footing is also provided when the property line is so close to one column that a spread footing would be eccentricity loaded when kept entirely within the property line. By combining it with that of an interior column, loads evenly distributed (Chen,1988).

2.14.2.4 Mat foundations

A mat or raft foundation is a large slab supporting a number of columns and walls under the entire structure or large part of the structure. It is a large concrete slab used to interface one or more columns in several lines with the base soil. It encompasses the entire foundation area or only a portion. It is used where the base soil has a low bearing capacity and spans over weak patches of the soil and thus the differential settlements are considerably reduced (Bowles,1996).

2.15 Protecting structures from disturbances caused by soil swelling

2.15.1 Footing size

When footings are employed for foundations, their sizes can be adjusted for any design contact pressure, thereby preventing expansion of the clay immediately below the footing. But at depths below the footing the load is distributed over an area larger than the footing which reduces the unit pressure on the clay. For this reason small footing carrying light loads can be lifted by expanding clays more easily than large footings carrying heavy loads, even though both are subjected to the same contact pressure. So adjustment in the spacing (distance between footings) and loads should be made as far as possible so that footings. Both near the surface and near enough to the water table (water stable conditions) under the structure carry the same load and are of the same size in order to prevent unequal (differential settlement results) uplift (upheaval) (Al-Rawas and Goosen, 2006).

2.15.2 Using deep footings

The building may be supported on footings at a depth below the surface near enough to the water table, so that the moisture content will not be affected by environmental changes. Precautions must be taken to prevent damage to the buildings by uplift on parts on the building by expansion of the clay between the footings and the ground beams, floors and other parts of building at ground (Chey, F.H., 1975).Thus the extension of footings to an active soil zone below the expansive clay level may offer sometimes the best solution depending on how thick is the expansive layer. The extension of independent footings to depths of up to 7.5m in hard desiccated clay could be done quite economically by casting piers with belled footing.

2.16 Mitigation measures

2.16.1 The best time to construct foundation

As many geotechnical engineers suggested that the best time to construct foundation in expansive soil is when the soil is not at its wettest nor at its driest condition, i.e., when the soil is near "equilibrium". However, it is usually impractical to wait for this optimum time to start building. Thus, it is important that the foundation be designed and built so that it will perform adequately under all of the normally expected conditions that the building will experience during its usable life time (Chen, F.H.1998).

2.16.2 The best way to avoid damage from expansive soil

The best way to avoid damage from expansive soil is to extend building foundations beneath the zone of water content fluctuation. The reason is twofold; first, to provide for sufficient skin friction adhesion below the zone of drying; and second, to resist upward movement when the surface soils become wet and begin to swell. Another way of mitigating expansive soil problems is to collect surface runoff and to limit surface infiltration during the rainy seasons (Holtz, 1973).

2.16.3 Backfill material under and around the building

If the foundation is a shallow foundation, one solution that has been used successfully is removing the expansive soil down to a specified depth and replaces it with a non-expansive soil. However, this is usually an expensive way to solve the problem. Sometimes the terrain lends itself to constructing an elevating pad of foundation soil beneath the foundation without causing the foundation cost to be exceptionally great. In either of the two instances where different soil is used other than what already exists at the building site, a non-expansive soil should be used. A "non-expansive" soil is usually considered to be a soil that has a plasticity index less than 20 and preferably less than 10.sandy or coarse silty soils meet this criterion, but because of their relatively high permeability, if water should ever be introduced in to this type of soil, it could travel throughout the soil mass, wet the underlying expansive soil, cause the heaving that the non-expansive soil was meat to prevent. If the house has a basement, the backfill soil ideally should be taken to prevent water from entering the backfill regardless of whether or not the soil is expansive or non-expansive. If the backfill is expansive, then unwanted lateral swelling pressures will be imposed on the basement wall. If the backfill soil is non-expansive and if a considerable amount of water collects in the backfill, the water will impose a hydrostatic pressure against the wall. Water collecting behind the wall can cause damage because basement walls are seldom designed for hydrostatic pressure unless the basement extends below the ground water table (Al-Rawas and Goosen, 2006).

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CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the study area

3.1.1. Location

Addis Ababa city overlies at the western margin of the Ethiopian rift valley and is a part of the western highland of Ethiopia and represents a transition zone between the Ethiopian plateau and the rift with poorly defined escarpment. The selected study sites are located in. i.e., Akaki Kality, Bole, Nifas silk and Yeka sub city (Fig. 3.1). The thickness of expansive soil varies from place to place from 2m to 10m. The highest thickness is found in Bole area and in Beklo Bet area it is about 5m thick (Kebede Tsehayu et al, 1990).

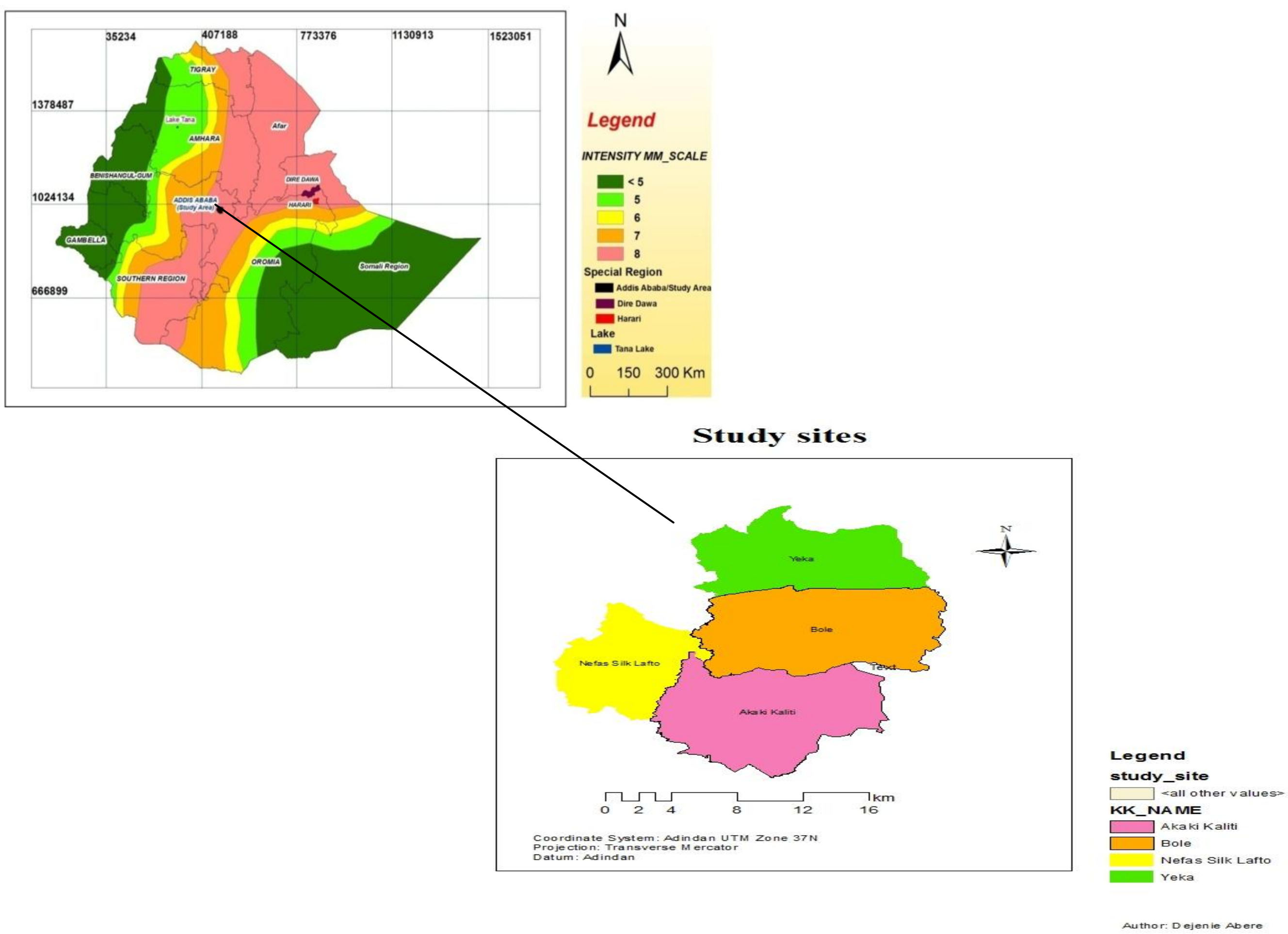


Figure 3.1 Location Map of the Study Area

3.1.2. Topography

Topographic relief has an important role in soil formation. In areas which are flat, the soil typically tends to get deeper quicker than the surface erodes away. On steep slopes, erosion usually takes place quicker than the formation of new soil beneath. The result is that flat locations typically have a deeper, more mature soil layer than do locations with a steep slope (Gilloth, 1962). The study area is on a flat to gently sloping topography with small sized erosion gullies crossing (Fig. 3.2).Many researchers mentioned that flatter slopes and poor drainage favor the formation of montmorillonite clay soil minerals.

3.1.3. Drainage

Addis Ababa lies within the Awash River Basin. The water divide between Awash River Basin and Blue Nile River Basin lies on the top of Entoto ridge. The catchment area of Akaki River basin that totally includes Addis Ababa area is divided in to two sub basins-the Big Akaki River (Eastern) sub basin and the little Akaki River (Western) sub basin (Fig 3.2).The streams of Addis Ababa drain towards south from Entoto ridge, south east from Mt. wecheca and Mt.Furi and towards south west from Mt.Yerer and other elevated areas of the eastern outskirts of the city. The potential streams in the city are little Akaki, Bantyiketu, Kurtume, Kebena, Ginifile, and Big Akaki. The drainage pattern is governed by the geology and physiographic set up of the area (Tamiru Alemayehu et al., 2006).

Figure 3.2.Physiographic and Drainage Map of the Study Area

3.1.4. Climate

Climate is the principal factor governing the rate and type of soil formation. The two most important components of climate are the amount and distribution of precipitation, and temperature. The temperature variable is adequately represented by mean annual temperature, which doesn't differ greatly from the nearly constant temperature in the lower part of the regolith. According to (Gilloth, 1962), the velocity of a chemical reaction increases by a factor of 2 or 3 for every 10 ℃ rise in temperature. The two main rain fall parameters most widely available are the mean annual total and the length of the dry season. Climate change could modify rainfall, evaporation, generation of runoff, ground water level and soil moisture storage. Changes in total seasonal precipitation and in its pattern of variability are both important in predication of alternate cycles of swelling and shrinkage (Gilloth, 1962).

3.1.4.1 Rainfall

In Addis Ababa, rainfall intensity variation is attributed to differences in Topography. The records from rainfall recording stations show that higher elevation like entoto receive higher rainfall than the lower elevated. In addition, the rainy seasons those receive higher rainfall which is starting from the month June to September.

Table 3.1: Mean monthly and mean Annual Rainfall of Addis Ababa

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	An.Average
Amount (mm)	13.7	37.4	68.8	93	76.4	119	235.4	242.5	143.3	32.7	7.2	5	1074

Source: National Meteorological Services Agency, 2016G.C

3.1.4.2 Temperature

The average temperatures are typically tropical to sub-tropical and fluctuate by 50C between the coldest and warmest months. (Griffiths, 1972; as cited in Habtamu Solomon, 2011).Fluctuating temperatures help break down mineral grains in rocks. Warmer temperatures increase chemical weathering. As a result, and being a tropical region, Addis Ababa has thick weathered profile (soil cover) in most of its areas, especially in gentle and flat lands. Although temperature has no direct influence on the engineering properties of foundation materials, its long term effect of accelerating weathering of near surface rocks cannot be denied. Weathering weakens the strength of earth materials through altering the mineralogy as well as their physical properties.

Table 3.2: Temperatures of Addis Ababa

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	An.Average
Amount (mm)	23.85	24.7	26	25.1	25.3	23.2	20.6	21	21.7	23.15	23	23	23.4

Source: National Meteorological Services Agency, 2016G.C

3.1.5. Soil and Rock Distribution

The soil development in Addis Ababa area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remain in places and form residual soils or transported and deposited in the low lying flat lands and depressions (TamiruAlemayehu et al, 2006).The differences observed in the type and development of soils in the city depends mostly on the topography, parent rock and the degree of weathering. Although there is significant difference in the degree of weathering on the slopes, mostly soils are highly eroded and result in thin soil cover. In the localities where the topography is plain to gentle there is thick soil profile. The type of parent material and the length of time to which the parent material is subjected to weathering, control the variation in the thickness of soil.

Most parts of Mekanisa, AyereTena, Kaliti, Akaki, Lideta, and Bole. The soil is black in color and the thickness varies from place to place primarily depending on the slope of the area.

KebedeTsehayu et al (1990) classified the soil units of Addis Ababa based on their origin as alluvial, alluvial fan, colluvial, residual and lacustrine (Fig.3.3).Lacustrine soils, alternatively named as black cotton soil, are found in Bole, Lideta and Mekanisa areas as these areas are flat and relatively low lying. Observations and tests show that the low lying flat areas around Addis Ababa are dominated by black cotton soils. These soils have extremely high plasticity and very high degree of swelling as compared to the other identified soil types found in Addis Ababa. The thickness of this soil varies from place to place from 2m to 10m. The highest thickness is found in Bole area and in Beklo Bet area it is about 5m thick (KebedeTsehayu et al, 1990).

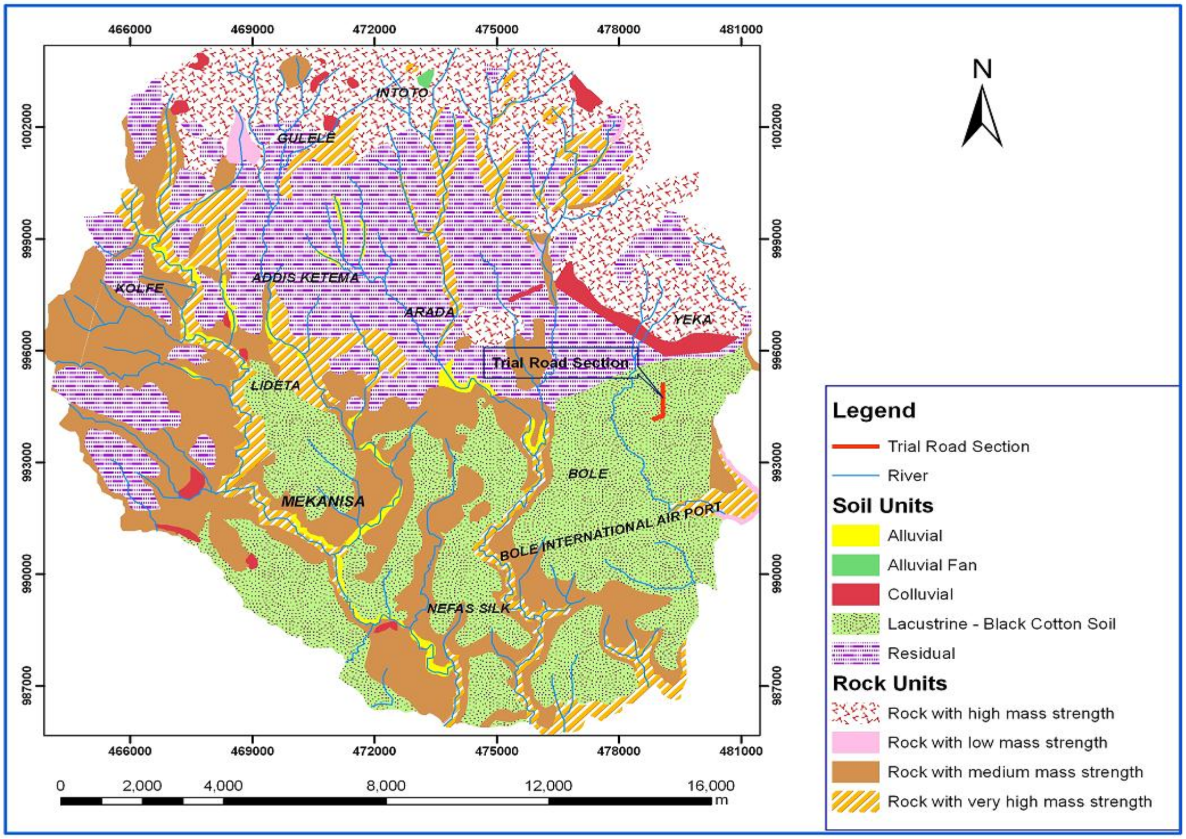


Figure 3.3. Engineering Geological Map of Addis Ababa (after Kebede Tsehayu et al., 1990)

The origin and the mineralogical composition of black and red clay soils of Ethiopia have been studied by (Morin and parry,1971).According to the investigation, black and red clay soils have formed over tertiary to recent basaltic volcanic rock which covers the greater part of Ethiopia plateau. Black clay soils are found in areas with poor drainage and low to moderate rainfall and contain montmorillonite as the principal clay mineral with accessory kaolinite and halloysite. The red clay soils have developed where rainfall is more plentiful and drainage is good and contain kaolinite and halloysite as the principal clay mineral with accessory montmorillonite.

3.2 Data Collection and analysis

3.2.1 Data Collection

In this research the data were collected through questionnaires for status assessment; field observation , measurement for defining the expansive soils' impact, soil sampling and laboratory analysis for soil characterizations.

3.2.2 Primary Data Collection

3.2.2.1 Questionnaire

Currently many numbers of condominium houses are being constructed under the administration of Addis Ababa housing construction project office. Accordingly, multiple contractors and consultants are engaged in this project. Two different questionnaires were prepared which a questionnaire for professional's employees and owner's of condominium houses.

Questionnaires were developed and distributed for each practitioners: foreman, site engineers, resident engineers and supervisors from both contractor and consultant sides. From newly foundations of condominium sites, a total of 84 professionals (42 from consultant and contractors office each) were randomly selected from the list of the workers of contractors and consultants of Bole Arabsa and Koyefeche condominium sites (Table 3.3).

Table 3.3.Professionals engaged in the Questionnaires

Selected study sites	Total number of respondent from Consultant Office	Total number of respondent from Contractor on site
Bole Arabsa 3	7	7
Bole Arabsa5	7	7
Bole Arabsa6	7	7
Koyefeche project 12	7	7
Koyefeche project 16	7	7
Koyefeche project 17	7	7
Total	42	42

The selections of the foundations were randomly selected without previous knowledge about the actual conditions, like foundation type, construction method, construction material and damages due to expansive soils. This approach eliminates the possibility of bias.

Further out of 45 blocks, 2 respondents were randomly selected and a total of 90 owners of condominium house respondents were selected from Jemo No.1, Yeka No.1 and Bole Ayatchefe. And more or less Bole Ayatchefe block numbers are one third of Jemo No.1 condominium site.

Table 3.4: Condominium houses which was being constructed on expansive soils

Service in Advance (constructed Condominium sites)	Selected No. of Blocks for this study	Two respondents were randomly selected from each blocks
Jemo No.1	15	30
Yeka No.1	15	30
Bole Ayatchefe	15	30
Grand Total	**45**	**90**

Note: *In Jemo No. one condominium site for the purpose of this research tilted block no.220 and 14 surrounded blocks are included.*

3.2.3 Field investigation and Observation

Out of 601 blocks 249 blocks were randomly selected for the purpose of field investigation and observation. As shown from table 3.3, the total numbers of blocks in the selected study sites are 601.However; in Bole Arabsa 3: five blocks and Bole Arabsa 5: two are not yet started to construct respectively.

Table 3.5: Foundation type in Koyefeche and Bole Arabsa site for G+4 and G+7

Foundation Type	Foundation type in Koyefeche and Bole Arabsa site for G+4 and G+7											
	Bole Arabsa 3		Bole Arabsa 5		Bole Arabsa 6		Koyefeche project 12		Koyefeche project 16		Koyefeche project 17	
	G+4	G+7	G+4	G+7	G+4	G+7	G+4	G+7	G+4	G+7	G+4	G+7
Isolated Footing	17	46	15	58	20	41	70	54	65	16	44	
Mat Foundation		8		11		9		7		40		80
Total blocks	**71**		**84**		**70**		**131**		**121**		**124**	

Note: During field investigation and observation; foundation type were taken only from the newly constructed condominium sites

3.2.4 Soil Sampling

Samples Locations

Soil sampling has been conducted only the constructed foundations of condominium which are constructed on expansive soils areas where Bole Arabsa 5, 6 and Koyefeche project 12, 16 and

17. Bole Arabsa 3 are exempted because much of the area is covered by boulders with the exception of some pockets (it is found that expansive soil like Bole Arabsa 5 and 6).

From Bole Arabsa 5 and 6, 5 and four samples were taken from the two sites respectively. AndKoyefeche project 12, 16 and 17 sites, three samples were taken from each project sites. And a total of eighteen samples were taken from Bole Arabsa and Koyefeche sites.

Table 3.6: Total number of soil sample from Koyefeche and Bole Arabsa site

Samples	Foundation type in Koyefeche and Bole Arabsa site for G+4 and G+7					
	Bole Arabsa 3	Bole Arabsa 5	Bole Arabsa 6	Koyefeche project 12	Koyefeche project 16	Koyefeche project 17
No. of soil samples	-	5	4	3	3	3

Note: Bole Arabsa 3 is exempted because much of the area is covered by boulders after bit depth from NGL with the exception of some areas. Visual observations made on Jemo no.1, Yeka no.1 and Bole Ayatchefe condominium sites to detect the presence of all signs of expansive soil in the area.

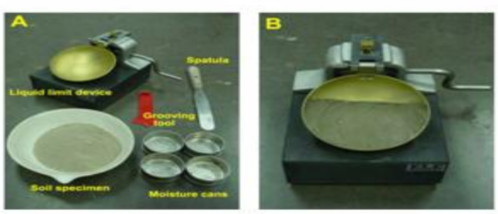
Samples Depth

Sampling depth was defined with a range of 1.5m to 2.5m to observe the depth variation in each site. Depth of excavation was dependent on the existing condition of the ground .i.e, in some places boulder was encountered after a bit depth from the natural ground level.

3.4 Data Analysis

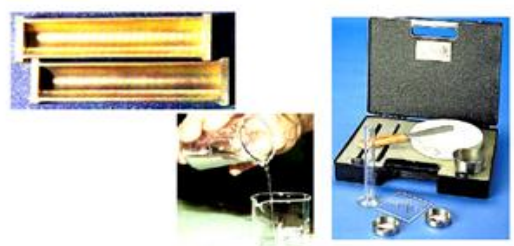
Data obtained from professionals and owners' respondents were analyzed using statistical package for social sciences (SPSS-23) software. From the soil sampling site, moist soil samples were collected using plastic bags and the plastic bags were tied to reduce the loss of natural moisture content. Soil samples tested in AAU, School of Earth Sciences, and Engineering Geology laboratory. Laboratory tests were conducted using the recommended method of testing that would not affect the true nature of expansive soils. The methods were more or less the same as those which had been used conventionally for testing soils for foundations of buildings purposes. The following apparatus were used:

Equipment used for Liquid limit test



Equipment used for Liquid limit test

Rolled threads for plastic limit determination.



Linear and volumetric shrinkage limit test equipments

Soil properties were measured and Analyzed in the laboratories. And ASTMD 4318-95 and ASTM 427-93[ASTM, 1996] were followed for testing procedure. Laboratory test includes free swell, water content, liquid limit, plastic limit, linear shrinkage and plasticity index. The laboratory data sets obtained were analyzed using empirical models, standard graphs and Tables.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Laboratory Test Result

The purpose of these tests is to classify expansive soil of Bole Arabsa and Koyefeche sites where the newly foundations of condominium houses are being constructed. The laboratory tests were conducted using ASTM D 4318-95 and ASTM 427-93 [ASTM, 1996] standards for laboratory testing. The methods which were employed are index properties and the results are given in Table 4.1.

Table 4.1. Index Properties' of the Soil in the Study Area

No	Site	Location	Depth (m)	Free Swell	Water Content	Linear shrinkage	Atterberg Limit		
							LL	PL	PI
1	Bole Arabsa 5	Sample No.1	2.5	20	36.15	23.33	54.82	31.42	23.4
2		Sample No.2	2.0	20	43.68	21.05	45.77	26.28	19.49
3		Sample No.3	1.5	20	38.45	22.65	53.15	32.65	20.5
4		Sample No.4	2.0	80	43.15	35.01	79.5	42.59	36.93
5		Sample No.5	1.5	20	51.55	20.59	47.89	27.64	20.25
6	Bole Arabsa 6	Sample No.1	2.5	60	27.70	24.65	69.75	39.49	30.26
7		Sample No.2	1.5	50	34.75	22.38	61.12	32.36	28.76
8		Sample No.3	2.0	70	30.85	28.12	70.45	38.15	32.3
9		Sample No.4	2.5	80	31.02	32.45	75.65	42.12	33.53
10	Koyefeche project 12	Sample No.1	2.0	50	27.65	24.5	60.25	29.65	30.6
11		Sample No.2	1.5	60	25.45	25.62	66.89	39.12	27.77
12		Sample No.3	2.5	50	29.78	22.15	63.98	32.15	31.83
13	Koyefeche project 16	Sample No.1	2.5	50	34.75	26.12	64.36	32.35	32.01
14		Sample No.2	2.0	50	34.75	23.25	61.12	33.62	27.5
15		Sample No.3	1.5	70	35.83	31.20	75.39	41.48	33.91
16	Koyefeche project 17	Sample No.1	2.5	50	28.78	22.74	58.25	25.36	32.89
17		Sample No.2	2.0	80	45.25	35.78	80.15	39.26	40.89
18		Sample No.3	1.5	80	33.17	34.32	77.65	42.36	35.29

Note: In more flatter areas smaller number of sample were taken. On the other hand on less flatter areas more samples were taken. More flatter areas favour the formation of more montimorillonite clay mineral soils. However, in areas of having slightest variation of topography comparing from flatter area, the distribution of expansive soil highly varied. And at different localities the distribution of expansive soil are highly varied from one localities from the other and not only each localities but also in a site.

As shown in table 4.1 it is impossible to conclude that whenever depth increase PI may not be decreased within the sampled depth i.e. 1.5-2.5m.For instance in Koyefeche project 17 at 1.5m depth the recorded PI value shows 20.25% , at same project in depth 2m PI value shows 40.89 % at 2.5 depth the PI value shows 32.89%.Therefore the conductor of this research observed, those contractors lay the pads when the colour changes or moving some distance from the natural ground level, they lay pads on the position without getting the actual bearing capacity of the soil. The above traditional way of labeling the pads speed up differential settlement problems, settlement of masonry below the grade beam, suspended of grade beam, column alignment problem and cracks of masonry walls in different segments. All the above problems happened beyond other contributing factors such as poor design, poor construction in line with poor workmanship, inadequate observation of construction processes, poor drainage have exacerbated the problem. As Chen F.H (1988) stated PI value ranges from 0-15,10-35,20-55 and35 and above are low, medium, high and very high plasticity index values respectively. Highly plastic soils have a property of high compressibility when saturated, poor shear strength when compacted and saturated, potential for high swelling and cracking, difficulty in moisture control during construction(poor workability),slow rate of construction so that pore pressure is dissipated safety, and causing some difficulties and time consuming procedure to provide fine filters particularly for large volumes.

Table 4.2.Classification of Soil Sample Test Results Based On Plasticity Index Values

Sites	**Plasticity Index**	**Number of samples**	**Description**		
			Medium plasticity	**High plasticity**	**High plasticity**
Bole Arabsa 5	10-35	1	✓		
	20-35	3		✓	

	35and above	1			✓
Bole Arabsa 6	20-35	4		✓	
Koyefeche project 12	20-35	3		✓	
Koyefeche project 16	20-35	3		✓	
Koyefeche project 17	20-35	1		✓	
	35and above	2			✓

Note: plastic Index (PI) can be used as a reasonable surrogate to indicate expansive soil. And5.5%, 77.8% and 16.7% showed that medium, high and very high plasticity index values respectively.

4.1.1 Soil Sample Test Result of Bole Arabsa

Bole Arabsa soil laboratory test contains nine samples. The two samples are found to be below fifty (50%) liquid limit and the rest seven samples showed high (53-79%)liquid limit. However, the plasticity index showed that out of nine samples five samples whose plasticity index are below 30% that ranges from 19.49% up to 28.76%.The remaining four samples have above 30% plasticity index ranges from 30.26% up to 36.93%(Fig 4.1 and Fig 4.2).The area shows higher plasticity index and soils of these properties can experience high shrink-swell potential and would exhibit damaging characteristics.

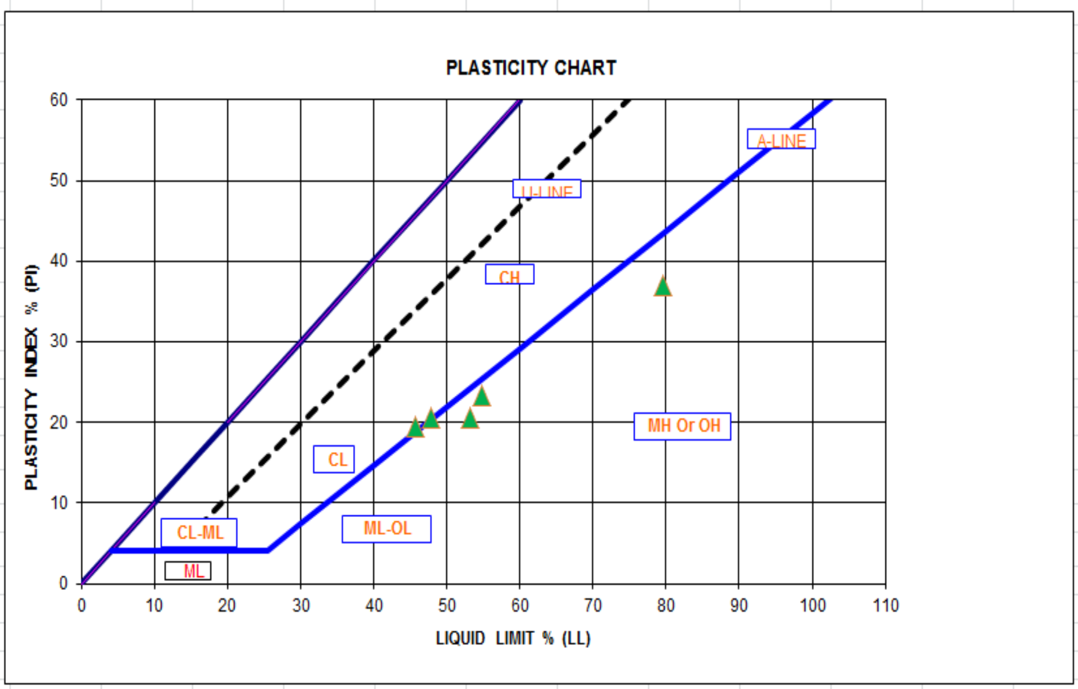


Figure 4.1.Distribution of Bole Arabsa 5 Samples on the Plasticity Chart

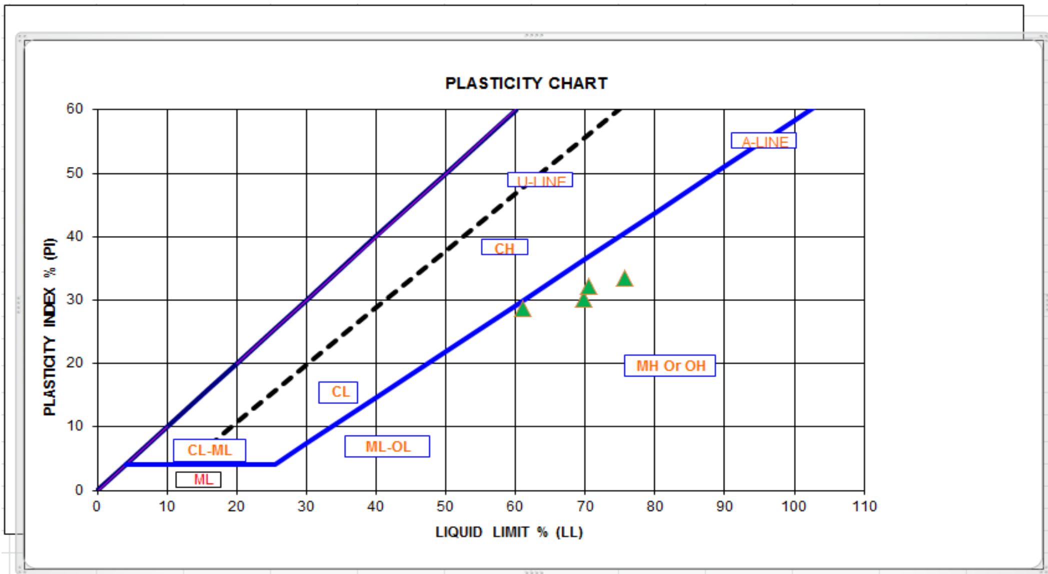


Figure 4.2.Distribution of Bole Arabsa 6 Samples on the Plasticity Chart

4.1.2 Soil Sample Test Result of Koyefeche

Similarity with that of Bole Arabsa site showed nine samples of soil test results. With regard to liquid limit only one sample constitutes 58.25%.The remaining eight samples range shown from 60.25% up to 80.15% liquid limit soil test results. The plasticity index results out of nine samples only two of them shown below 30% these are 27.5% and 27.77%.The remaining six samples shown between the range from 30.6% up to 40.89% plasticity index. Therefore koyefeche has very higher plasticity index (Fig 4.3 ,Fig 4.4 and Fig 4.5).

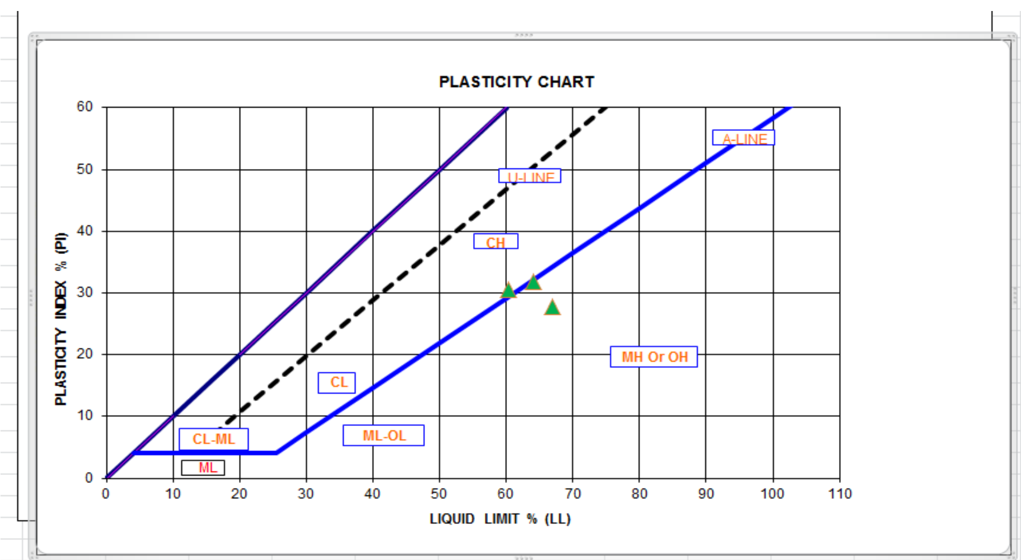


Figure 4.3.Distribution of Koyefeche Project 12 Samples on the Plasticity Chart

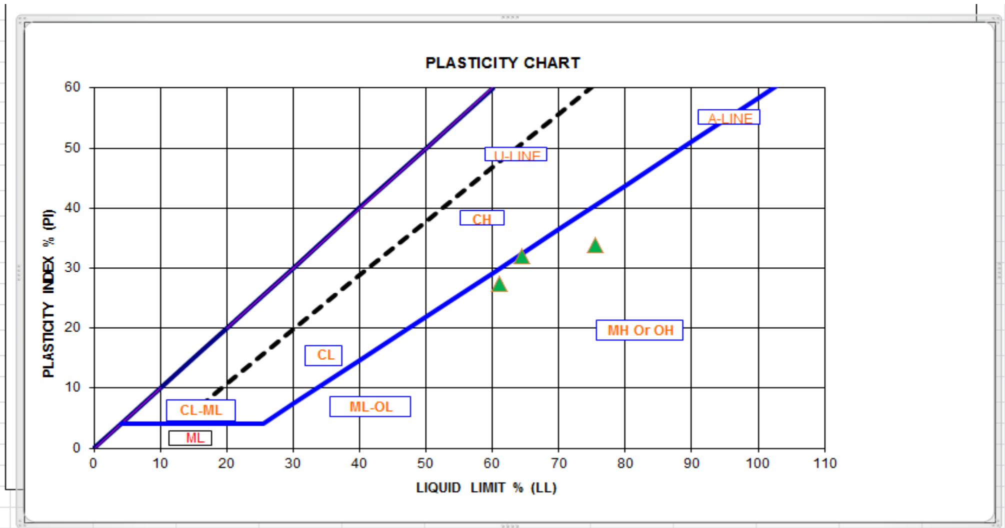


Figure 4.4.Distribution of Koyefeche Project 16 Samples on the Plasticity Chart

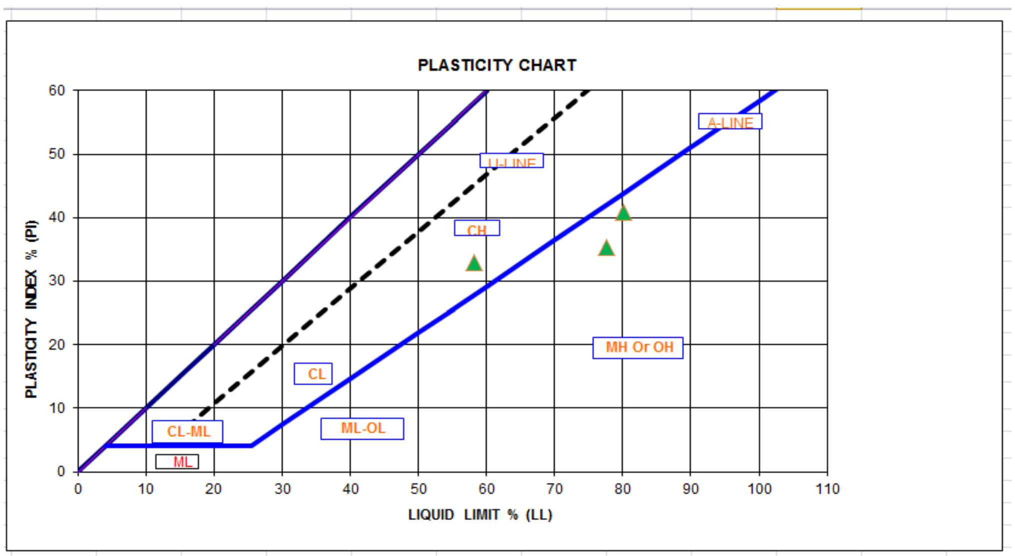


Figure 4.5.Distribution of Koyefeche Project 17 Samples on the Plasticity Chart

4.1.3 Bole Arabsa and Koyefeche Sites Based On PI Value

Comparing Koyefeche site with Bole Arabsa site, Koyefeche shows higher plasticity index. As it is observed in the plasticity chart, most of the soil test results of the study area falls MH mean elastic silt, which shows that the soil is potentially expansive. And soils of these properties can experience high shrink-swell potential and would exhibit damaging characteristics.

4.2 Professionals Respondents, field investigation and observation on the study sites

4.2.1 Backfilling

n=72

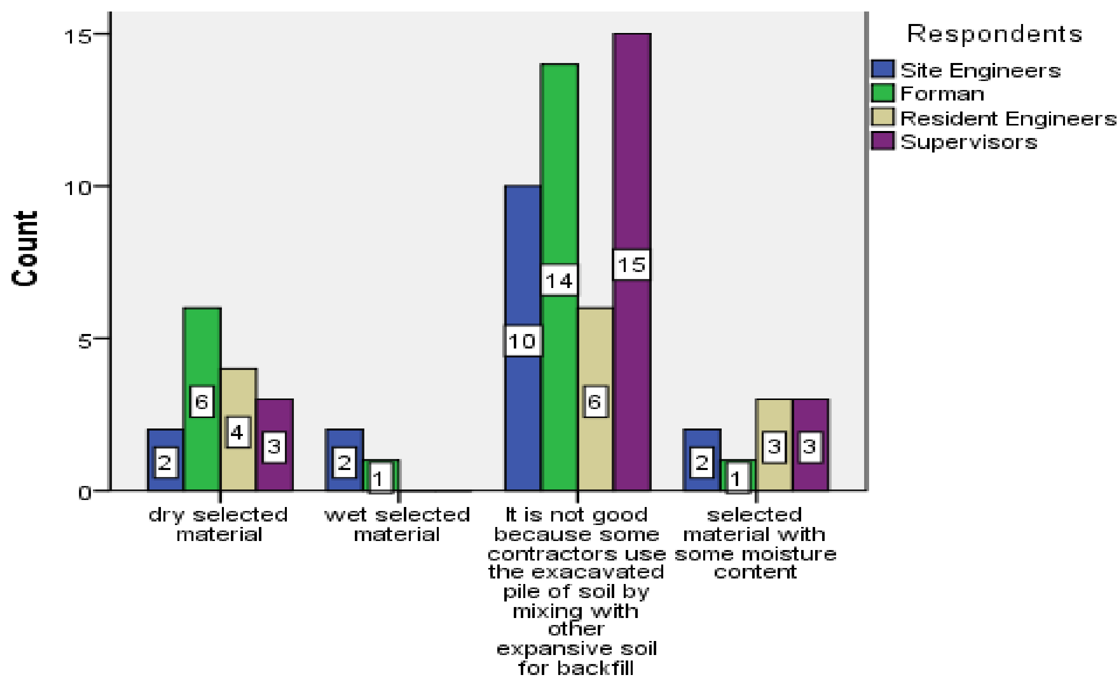


Figure 4.6.Backfilling History

Most of the professional respondents believed that the backfills had not been made any change for proper replacement and compaction, as non-proper backfill material had been used; mostly the backfill material was a simple mixture of the excavated material with soils of higher PI values. Generally, the building faced to many problems such as differential settlement problems, cracks in the walls and floors, settlement of masonry wall below the grade beam and sticking doors and windows.

4.2.2 Compaction

Mostly compactions are done using hand compactor (by tamping with manual wood forms) not layer by layer, which are difficult to maintain the compaction requirement in expansive soils. It is from this fact that the backfills underwent moderate settlement and up on wetting, the backfills compressed (consolidated) under their own weights. Some poor soils were supposed to be removed and to be replaced with structural soils and fully compacted with conventional equipment to standard relative compactness (full proctor density).

Most of the damages of the newly foundations and constructed of condominium houses not only caused by expansive soils but also due to poor compaction and backfill material, uncontrolled drainage and lack of supervision during construction.

Bole Arabsa 3: Compaction not layer by layer

Bole Arabsa 5: Compaction by hand compactor

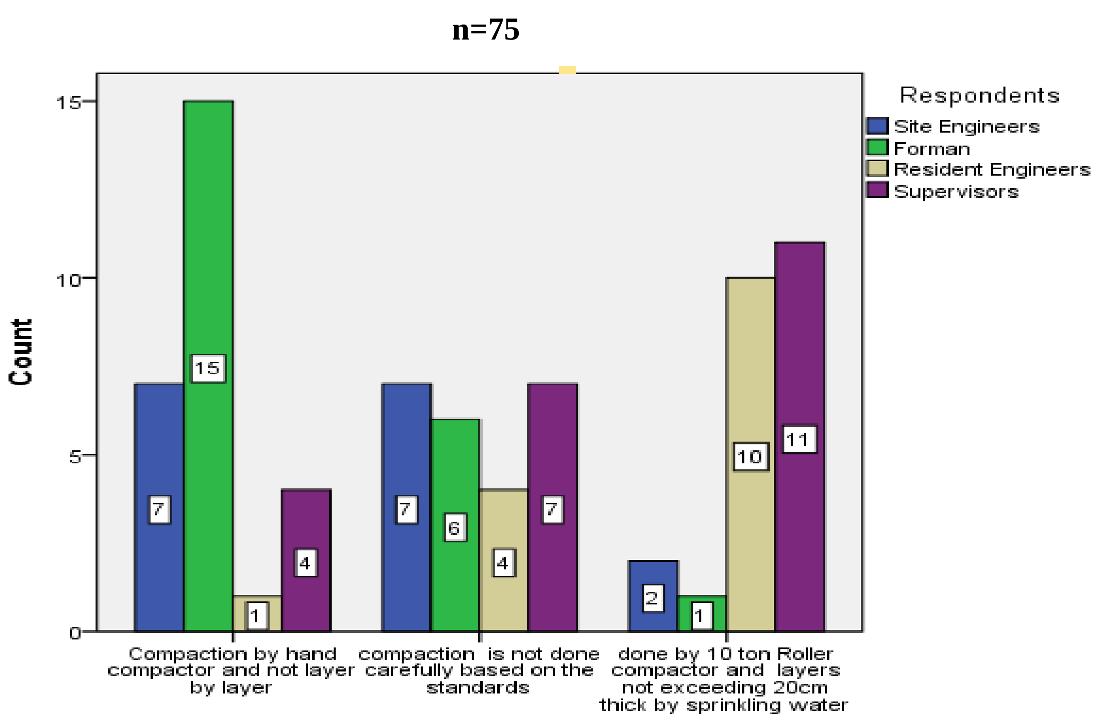


Figure 4.7. Compaction History

4.2.3 Standard of Workmanship

n=79

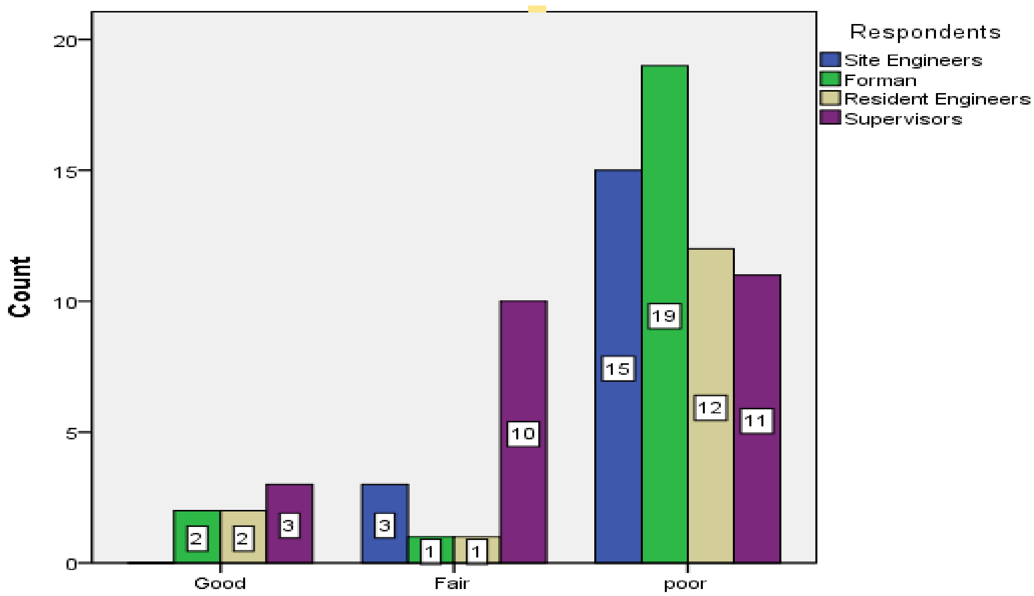


Figure 4.8. Standard of Workmanship

As shown in the above figure 4.8 poor workmanship cannot follow proper specifications, scientific procedures and principles during construction and therefore, that aggravates the damage of condominium houses.

4.2.4 Foundation Type and Depth

Mostly foundation design of condominium houses are being adopted irrespective of the site soil conditions. Isolated footing is the most common type of footing even in sites where expansive soils are abundant. It is also observed that different footing practices are engaged for the same soil type in the same site.

Respondents indicated that there is a natural interest from the client, Addis Ababa housing construction project office, to minimize foundation cost by employing isolated footing without giving much emphasis to the soil type.

There is a disparate finding between the practical situation and what professionals responded in the questionnaires regarding the foundation depth. In many parts of the study areas, it was observed that depth is defined by the change in color, avoiding only top soil, while excavating in-depth for foundation preparation. This is common feature in most parts in the study sites (Appendix, 4).

n=80

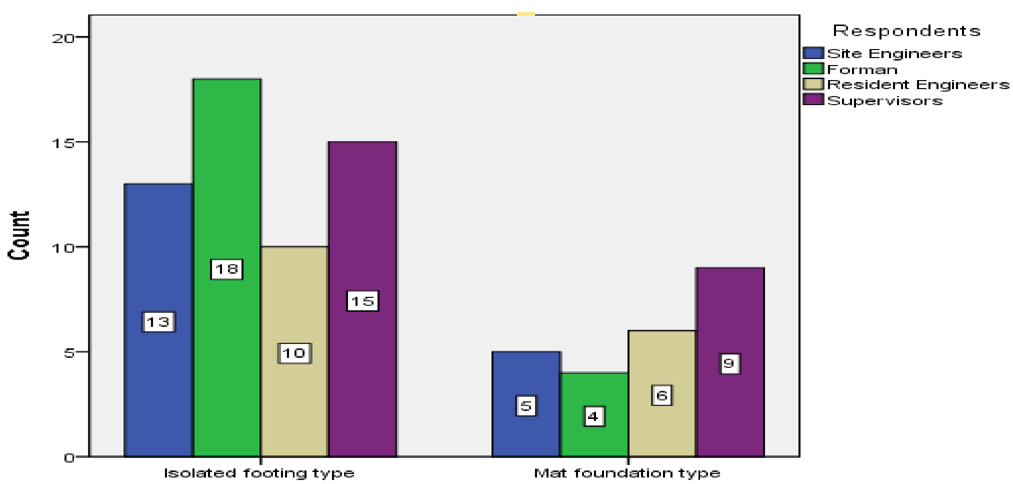


Figure 4.9. Foundation Type

n=79

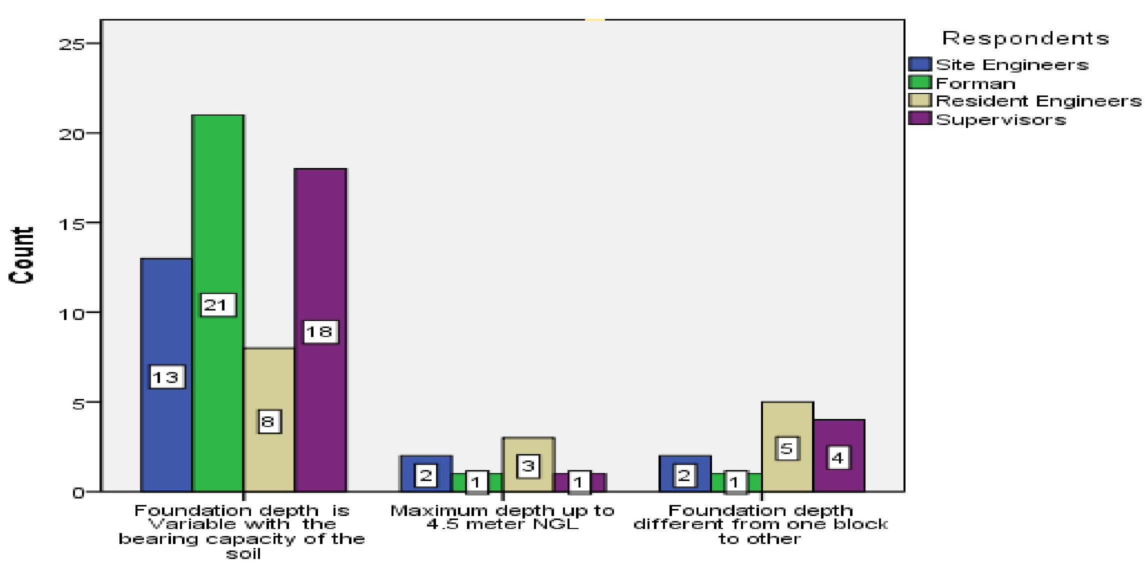


Figure 4.10. Foundation Depth

As shown in figure 4.10 it is observed that foundation depth differ from one block to another for the same soil type in the same site. And this negligence act came from lack of supervision responsibility, the absence of check and balance.

Bole Arabsa 5: Mat Foundation

Bole Arabsa 5: Isolated Footing

Koyefeche project 16: Selected for isolated footing

Figure 4.11. Different Foundation Footings [Isolated and Mat] Used Within the Same Soil Type

As shown in figure 4.11, in Koyefeche and Bole Arabsa many blocks have isolated footing types of foundations despite the need of mat footing as the area is constituted by a thick expansive soil. Mostly the failures of the newly foundations of condominium houses are through lack of proper site investigation and inadequate design which means in many instances the design of condominium houses seemingly similar design implemented in every corner of study area. It should have been on the basis of the soil.

4.2.5 Types of Damages on the Newly Foundations of condominium

From 249selected blocks, 46.58% of blocks demonstrate settlement of masonry wall below the grade beam; 53.41% of blocks showed problem of suspending grade beam; and18.07% of blocks column alignment problem due to suspension of grade beam. It is observed that 41.36% of blocks have been cracked of masonry wall in different segments. The damage in general ranges from dormant to moderate in 24.89% of blocks.

Table 4.3.Types of Damages on the Newly Foundations of condominium

The newly foundation sites		Total No. of blocks	Selected number of blocks for this study	Visible Blocks damaged on the newly foundations				
				Settlement of masonry wall below the Grade Beam	Suspended of Grade Beam	Column alignment problem due to suspended Grade Beam	Cracks of Masonry Wall in different segments	Dormant to moderate damage
Koyefeche project 12	G+4	70	37	26	22	8	18	11
	G+7	61	21	14	15	6	13	6
Koyefeche project 16	G+4	65	29	18	19	7	15	10
	G+7	56	29	15	21	9	12	8
Koyefeche project 17	G+4	44	21	10	14	8	13	7
	G+7	80	37	23	24	5	14	13
Bole Arabsa 3	G+4	17	9	2	3	-	1	-
	G+7	54	16	2	4	-	5	2
Bole Arabsa 5	G+4	15	7	1	2	-	2	-
	G+7	69	14	2	3	2	4	2
Bole Arabsa 6	G+4	20	11	1	3	-	2	1
	G+7	50	18	2	3	-	4	2
		601	249	116	133	45	103	62

Figure 4.12.Koyefeche Project 12

As shown from figure 4.12, masonry wall expand to the side area and the cause of the problem lies on the workmanships and also this block showed differential settlement problems

Figure 4.13.Koyefeche Project 12

As shown the above figure 4.13, such problems are enormous in koyefeche project 12 and showed the impact of black cotton soil on the newly foundation. The soils which hold building tend to expand to side area. Internal confining pressure which pushes the masonry walls Because of the above reasons cracks happened in areas where weak joints are available (found) as the witness of field observation. However; in the above figure differential settlements, uniform settlements, tipping settlements are not observed.

n=75

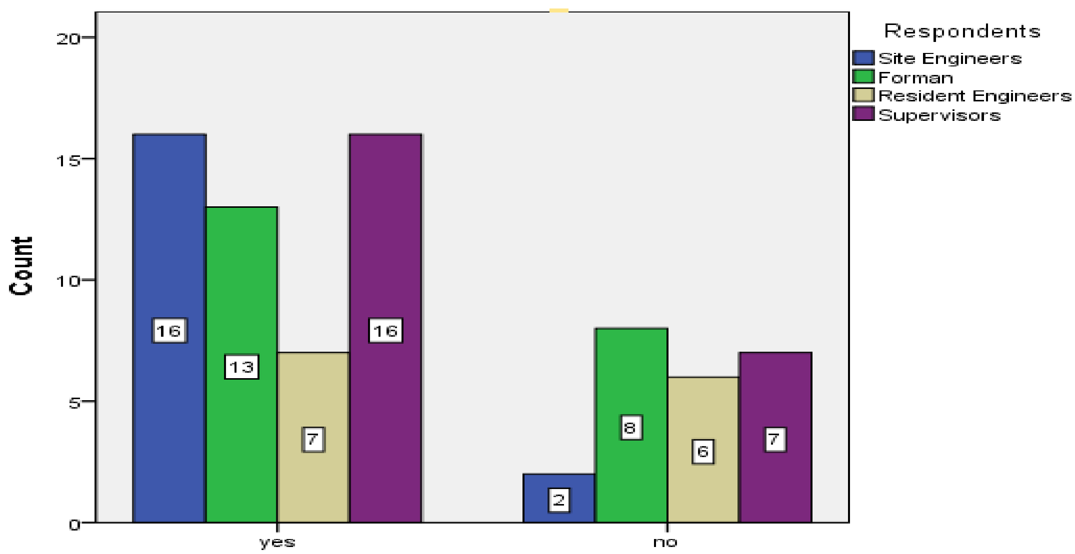


Figure 4.14.Suspension of Grade Beam below the Masonry Wall

Figure 4.15.Koyefeche Project 17

Figure 4.16.Koyefeche Project 16

In figure 4.15Koyefecheproject 17 and figure 4.16Koyefecheproject 16 as the picture displays and it showed differential settlement problem and settlement of masonry wall below the grade beam. In this regard joint parts are exposed to cracking little by little whenever the structural loads are increasing. In addition to the absence of any support from the bottom having crack is inevitable. Then as time goes on load arrangement problem results happen. Apart from the above each column load becomes cause by itself together with the supper structure influence. For example currently we are looking differential settlement even if the load is limited. Therefore grade beam bending movement is clearly visible if the load is imposed (burdened) beyond the limit. In most cases in the study sites footings and slabs are placed directly on expansive soils without proper compaction and backfilling. Different codes set the limiting settlement for the type of the structure and foundations. In the case of EBCS-7, 1995 the allowable settlement 50mm and 75 mm for sandy and clay soil respectively. These settlements depend on a number of parameters basically soil type.

Figure 4.17.Koyefeche Project 12

Figure 4.18.Koyefeche Project 16

The block as shown in figure 4.17 is found within Koyefeche project 12 on the side of the road margin or pavement of the road. The block is visible to any by passers; the workmanships have tried the best level to cover the cracked part. After crossing this block, you find a lot of cracked buildings with other defects. Apart from the above figure 4.17shares the same problems with figure 4.13.Nevertheless, the lateral earth pressure detached the masonry wall a parted each other and slide to the external side. Little by little lateral earth pressure commutatively with super structure cause to tending tumbling of the masonry wall entirely. However; In Figure 4.18koyefecheproject 16, currently the visible problem is differential. It could be possibly caused by failures selecting materials, workmanship, and compaction problem. Areas where differential settlement is existed, flooding is common/available and results equilibrium moisture disturbance. The problem creates moisture disturbance happens on a round the footing and the basement where the masonry wall existed and footed areas finally.

Figure 4.19.Koyefeche Project 17

Figure 4.20.KoyefecheProject 12

In this Figure 4.19 and 4.20 the problems observed in this blocks were selecting materials and compaction. If suspended happens on the spot of loading and grade Beam bends, the cause of the problem lies on the workmanships. The grade Beam is designed not in the manner of suspended way rather the design is made on the surface. So we can understand from the above pictures, there is an area which concentrated load presumably that results cracking. This concentrated load makes the grade beam bending and results cracking as well.

Finally, the cumulative problems jointly brings the over equilibrium disturbance. Beyond /apart each column is forced to carry unexpected load beyond the limit of prior design capacity. In addition to this columns are exposed to carry extra loads. Perhaps, they may tend to compact the open space to empower support grade beam to carry any load that come from super structure. In my opinion it is hardly possible empower supporting capability of the burden of the load. Because from the early start they failed to solve the problem but now they have tried to overcome the short comings by compacting now and then.

4.2.6 Professional Worry Regarding Condominium Site

n=79

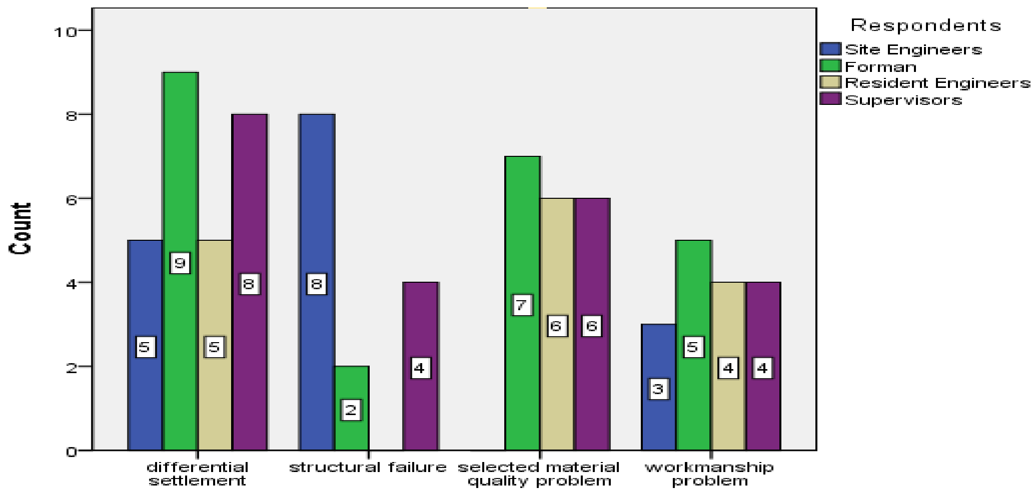


Figure 4.21. Professional Worry Regarding Condominium Site

As shown in figure 4.21, out of 79 professional respondents majority of them mentioned their worry regarding condominium houses such as differential settlement, structural failure, selected material and workmanship problems.

4.2.7 Owners' Perception on constructed condominium houses

The Crack, Specific Crack Location and Pattern

n=81

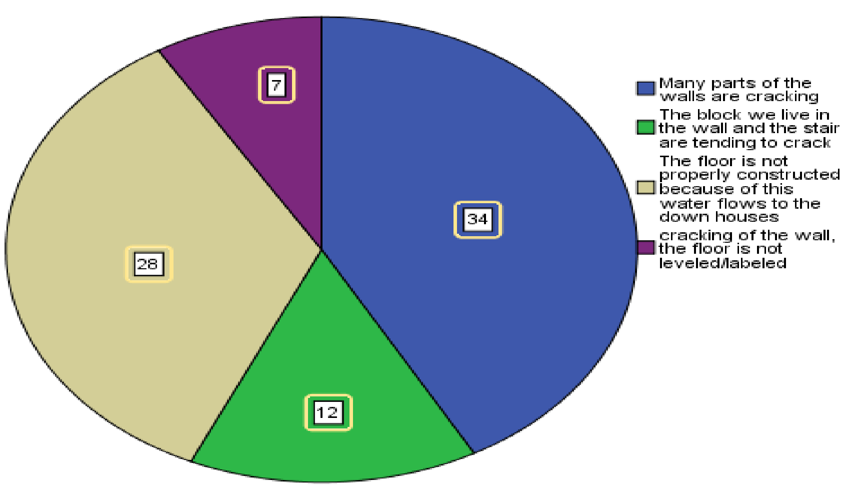


Figure 4.22. Crack Location and Pattern

As shown in figure 4.22,out of the total respondents 34 respondents mentioned that many parts of the walls are cracking and another point mentioned by 28 respondents the floors are not properly constructed because of this water flows to the down houses.these things make them difficult to live with this situations and it is not easy for maintenance.The damages occurred on walls are more than that occurred on floors.

n=84

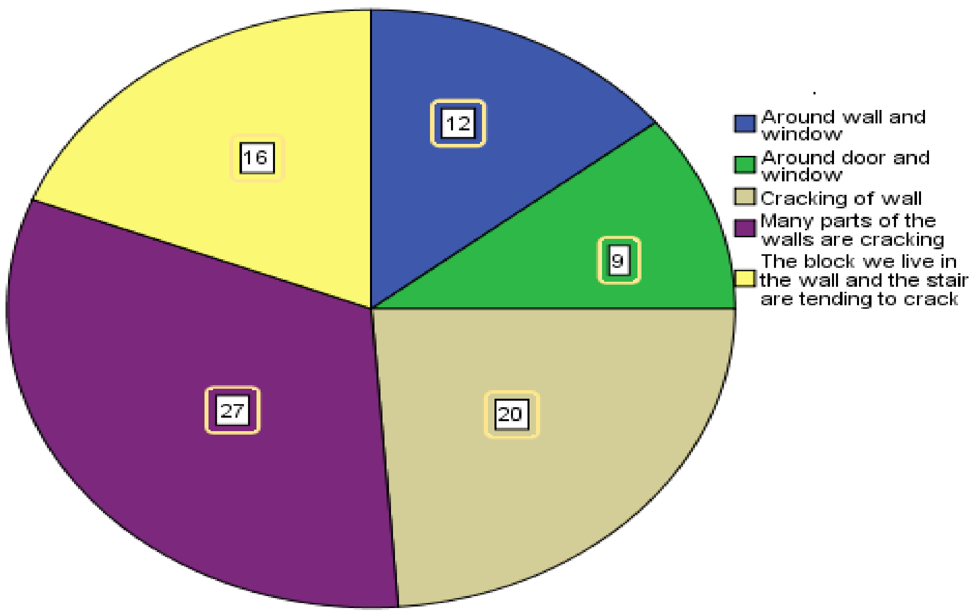


Figure 4.23. Specific Crack Location and Pattern

In this study owners of condominium houses were also asked to tell the specific crack location and pattern. According to the above figure 4.23, 27 respondents mentioned many parts of the houses wall cracked. Other 20 respondents said cracking of wall.

4.2.8 Cause of Cracks and Estimated Crack Size

n=82

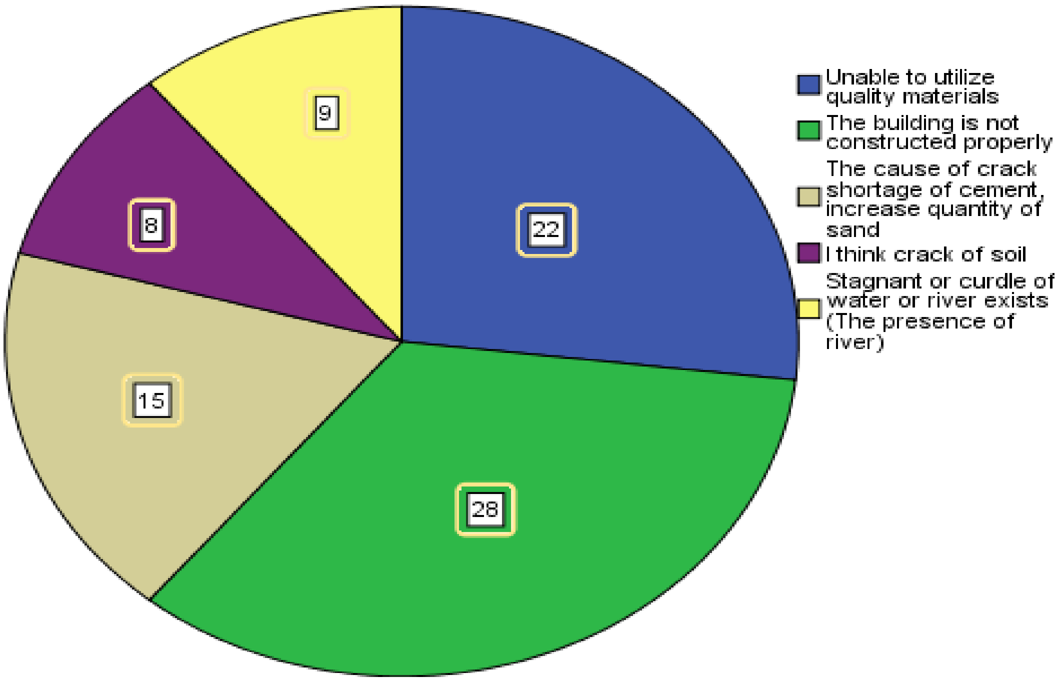


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Figure 4.24. Cause of Cracks

This figure 4.24 shows from the total of 82 respondents 28 respondents justified/blamed the cause of the crack should fall on; the building is not properly constructed. Others 22 respondents shift the blame, inability of using quality material. In the early life of cracking of the building may be inevitable. Cracks result from drying out or taking up of moisture or from the initial drying out of material that cannot be avoided. However; the respondents mentioned that as the day goes on little by little the crack size is increasing.

n=83

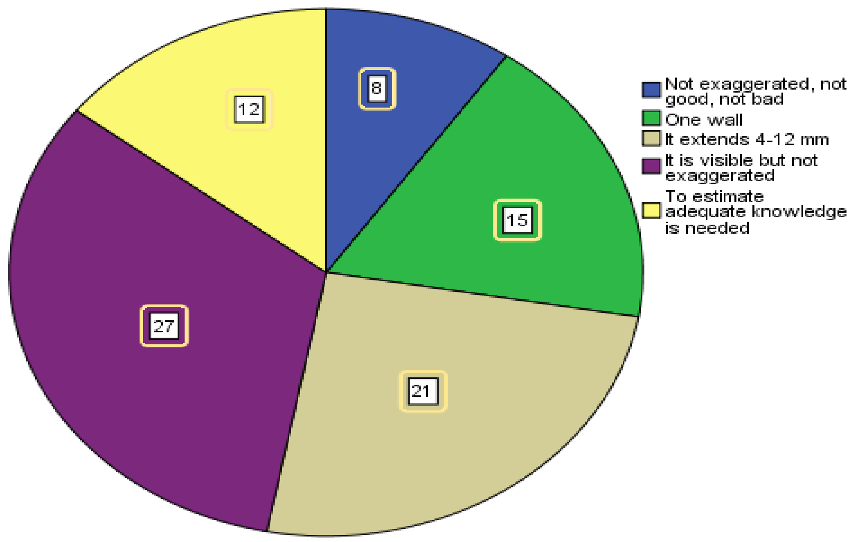

Figure 4.25. Estimated the Crack Size

According to the respondents in figure 4.25 ,the crack size it is visible but not exaggerated and some other 21 numbers of respondents mentioned that damage extends from 4-12mm.This indicates the damage is from slight up to moderate cracks.However, as the day goes on little by little the crack size is increasingly.In their observation it is inevitable approaching in severe condition in the near future.

4.2.9 Parts of Damaged and Needs Remedial Measures

n=85

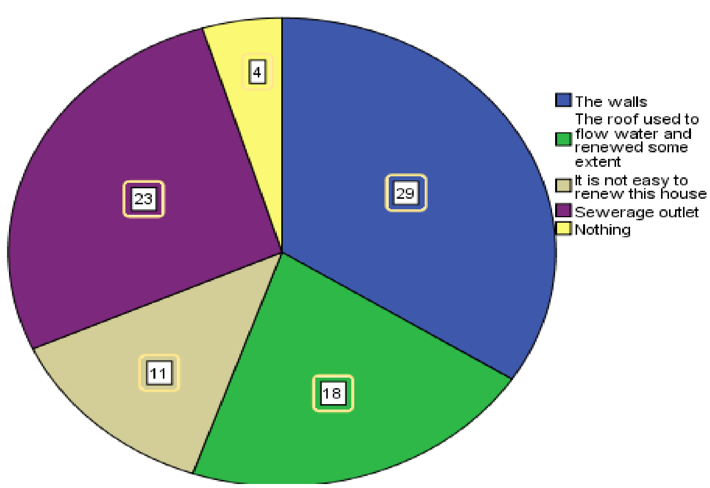

Figure 4.26. Parts of Damaged and Needs Remedial Measures

4.2.10 Exterior Wall Cracking

Figure 4.27. Exterior Wall Cracking Due to Differential Settlement Problems (Yeka-Ayat Block 352)

This figure 4.27 shows exterior wall cracking which is covered by cement has been seen by everybody. Pointing or maintenance work by the block inhabitants. Cracks found in condominium, whose pattern are very similar in many cases ranged from Slight cracks to moderate cracks. Most of the cracks originated in the corners and radiated either diagonal pattern of cracking. Some condominium had developed diagonal cracks with a stair-step pattern in blocket walls. They classified as slight to moderate cracks degree of visible damages. Diagonal cracks in the walls, sticking doors and windows, cracks in the floors are the indicators of soil movement. Besides that, cracks may be an indication of instability of the structure. Geotechnical engineers mentioned that slight movement also can cause cracking to large building. Other contributing factors for the damage of condominium houses such as poor design, poor construction in line with poor workmanships, and inadequate observation of construction processes, poor drainage have exacerbated the problem.

4.2.11 Tilted block 220 at Jemo No.1 Condominium Site

Figure 4.28. Jemo No.1 Condominium Site Block 221 Maintenance of Foundation Walls

The main source of soil moisture changes in the soils is rainfall. Other sources include poor drainage system and poor roof drainage, plumbing leakage and wet spots around the foundation and overwatering.

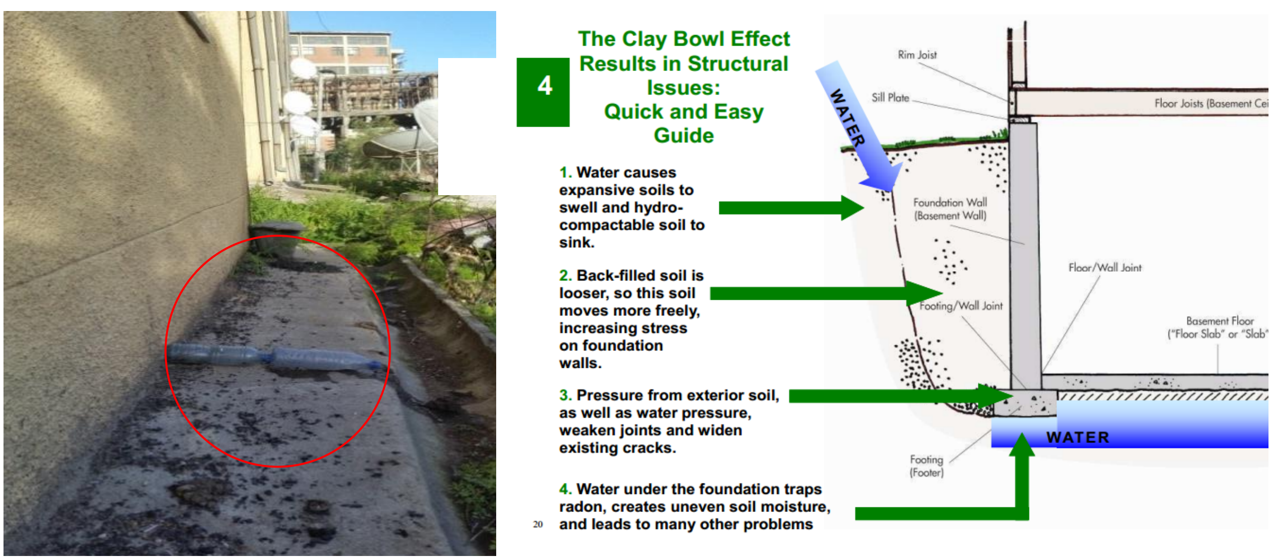

Figure 4.29. JemoNo.1 Condominium Block 220 pavement at the back side

The clay bowl effect which means moisture is an essential element to soil it is a lubricant that traps air and allows soil particles to slide together. Too much moisture and the ground become muddy and unable to bear weight. Too little moisture and the soil breaks in to its individual particles and blows away.

Block 220 has almost 2(two) shoes or two water bottle length pavement whereas block 221 and 219 have a bout 4(four) shoes or four bottle length pavement each from the foundation walls. This block 220 is showed tipping settlement and residents who fully left the entire block. Water which flows from the three block stations approaching to footing up on the above moisture is disturbed. As the picture shown the water percolates through the foundations. The venue of this block compound there are 6 (six) blocks and Out of six blocks five blocks selected for the purpose of this study. The researcher conducted detail studies like differential settlement, detaching of the wall from the pavement and the building crack marked. In some areas the houses are built in better way, for example if the contractor constructed nicely the other follows his shoes. By the same taken/logic in some occasions there is a presumption/exception collapsing of block 221.there is a possibility a contractor may be given two blocks. The contractor who constructed block 220 may construct other block in this compound. This shows all contractors who deployed on the five blocks are responsible for failures of the blocks with other concerned bodies. In general many of the respondents mentioned that the failures of Block 220 were directly attributed the concerned body. Respondents believe that the damages through use of inferior material, ignorance and negligence.

Figure 4.30.The front image of tilted block 220 at Jemo No.1 Condominium Site

According to the reflection of block 221 residents block 220 began tending to fail before the chanced/lucky people had joined the block. Then people started talking the vergin of failurity. While information was on progress/prevailing and then they would be residents reported to the government finally the gov't taking in to consideration their application. Some of them entered in to the open block, the others transferred to Jemo No.3condominium site.

4.2.12 Source of the Leak

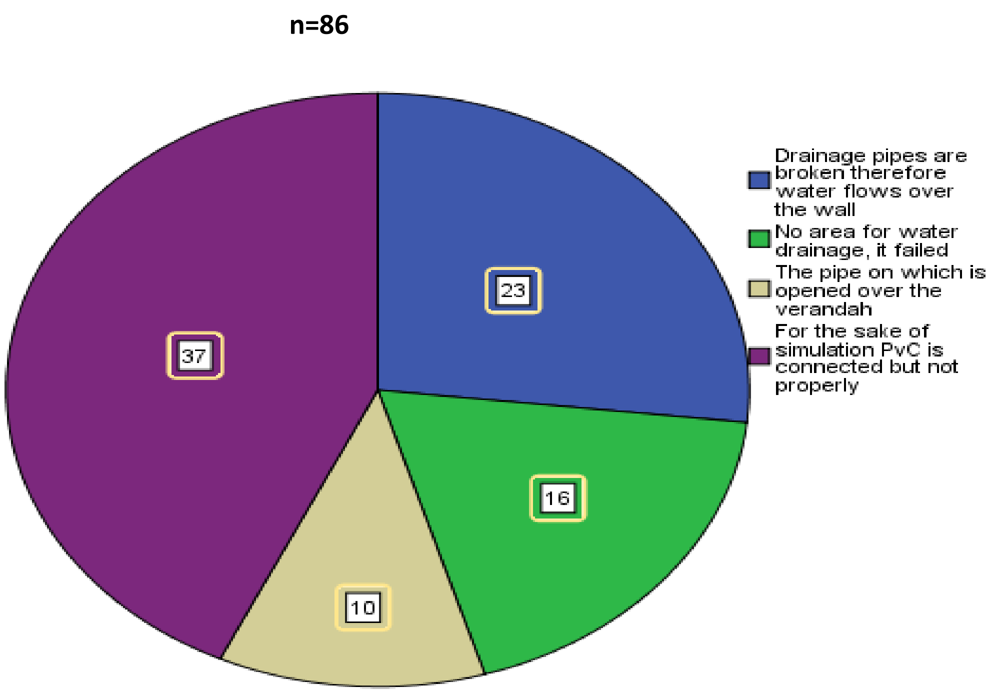

Figure 4.31 Source of the Leak

As shown from this figure 4.31,the majority of the respondents mentioned the drainage pipesare maintained and again broken many times.And this situations facilitates early failure of the building because of the drainage water that come from different directions.

Good gutters and downspout are necessarly to direct rainwater away from foundations.Most of the condominum houses surveyed had neither proper disposal of rainwater nor proper drainage away from the foundation or floor slab.many of the respondents don’t have clear idea of the effect of improper disposal of rainwater to the foundations.

4.2.13 Areas Where Condominium Site Are Well Constructed

n=81

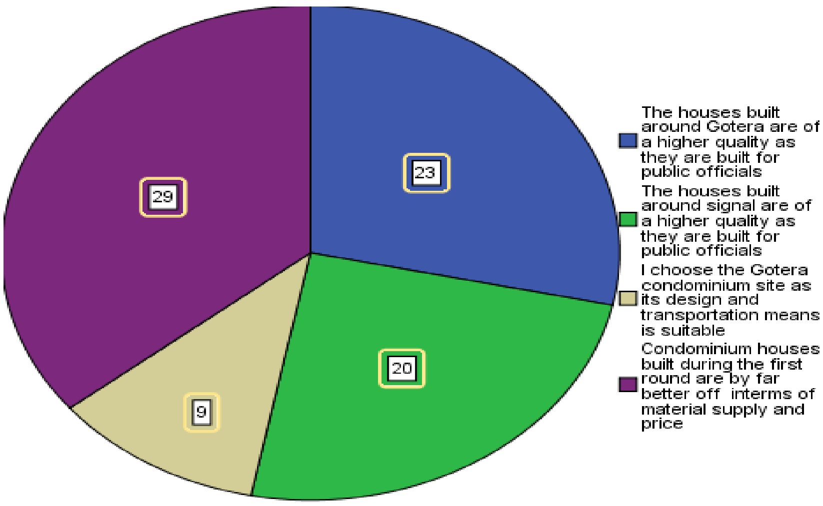

Figure 4.32. Areas Where Condominium Site Are Well Constructed

As shown from figure 4.32 Majority of repondents reported on the questionnaire the former condominiums have better quality than the recent.many the defects are observed on the newly constructedbuildings.even price is good as we Compared with newly one.

4.2.14 Owners Worry Regarding Condominium Site

n=87

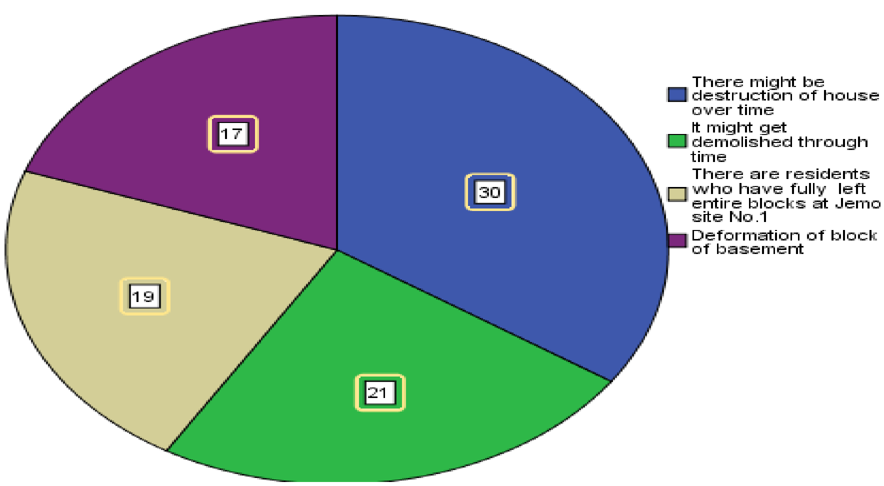

Figure 4.33. Owners Worry Regarding Condominium Site

As shown figure 4.33, many of owners repondents worry regarding their house there might be destruction of house over time because of many related problems that mentioned in this paper

4.3 General Discussion

Mineralogy and geotechnical characteristics of the soils in Addis Ababa in the east and southern east direction they are active and have a shrink-and swell potential. Visual observations made during a physical walk-through inspection detected all signs of expansive in the area. Development of surface shrinkage cracks (soil desiccation) during the extended dry season was viewed critically as the first indictor of the possible soil shrinkage and expansiveness. Furthermore, the general visual observations of the soil physical properties found that it was hard, densely packed and fissured during the dry seasons.

During the rainy season, the soil becomes sticky and plastic, confirming the presence of expansive minerals. The soils are mostly in greyish colour which is another indicator of the presence of expansive minerals. Visual examination of condominiums in the case study area revealed some of interesting discovery. Damages in lightweight structures were mostly related to the absence of full structural design (non-engineered properties) triggered by the presence of expansive soils, while the rest had to do with the poor construction methods used.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research the following conclusions are drawn:

- The soils in the study area exhibits high plasticity Index; out of 18 (eighteen) soil samples test result of plasticity index; 5.5%, 77.8% and 16.7% showed that medium, high and very high plasticity index values respectively. Based on the laboratory soil tests result as compared from Koyefeche site and Bole Arabsa, Koyefeche was found to have very higher plasticity index.
- It was observed that soil tests for each block prior to construction are not carried out by contractors for their contracting blocks in the study area. Moreover, the pad is founded on the basis of either color's change in the soil formation or encountering of rock fragments.
- On the newly foundations of condominium sites different damage have been observed. From 174 selected blocks, 106 blocks demonstrate settlement of masonry wall below the grade beam; 115 blocks showed problem of suspending grade beam; and 43 blocks column alignment problem due to suspension of grade beam. It is observed that 85 blocks have been cracked of masonry wall in different segments. The damage ranges from dormant to moderate in 55 blocks
- Most of the damages of the newly foundations and constructed of condominium houses not only caused by expansive soils but also due to poor design, poor construction, poor workmanship, uncontrolled drainage and lack of supervision during construction.
- Cracks found in many condominium houses whose pattern are similar in many cases ranged from slight to moderate crack damage. Out of 81 respondents 34 respondents mentioned that many parts of the walls are cracking. Diagonal crack at the walls and corner wall crack are typical crack pattern, exterior severe wall diagonal cracking is seen during field observation and damages occurred on walls are more than that occurred on floors.

5.2 Recommendation

- Study area has high plasticity index and so that replacing the original top expansive soil with compacted non-expansive backfill to depth below which the seasonal moisture content will tend to remain constant.
- Poor construction in line with poor workmanships, Poor design, and inadequate observation of construction processes, poor drainage has exacerbated the early failures and damages of condominium. Therefore; it is recommended to apply all existing available theories and practices for the design and constructions of condominium houses located in expansive soil areas in Addis Ababa.
- Poor supervision contributed to low quality works and it will be for the officers assigned for such duties must supervise projects under construction carefully so that contractors follow the proper specifications.
- Poor drainage makes the water percoletes through the foundation and that disturb the moisture content of the soil and therefore; the overall grading must provide for positive drainage away from the foundation direct to the concrete channel drains. The channel drains should again discharge water away from the foundation.
- At present, the construction regulations are not fully enforced. Consultants, Contractors and property owners paying little or no attentions to the damage of condominium house. It will take dedicated efforts to bring about a change in this state of affairs in such unregulated system.

REFERENCES

Alemayehu Tefera and Solomon Yohannes (1986).Investigations on the expansive soils of Addis Ababa, *Civil Engineering Department*.**7**:1-9.

Al-Rawas, A.A. and Goosen, M.F. (2006).*Expansive soils: Recent advances in characterization and treatment*. Taylor & Francis Group, London, UK, 570pp.

AyalewLulseged, (1999). Causes and mechanisms of slope instability in Dessie town, Ethiopia", *Department of Engineering Geology, Technical University of Clausthal, Department of Engineering Geology, Clausthal-Zellerfeld, Germany*.

Bary, I.M. (1986).The influence of Trees and Shrubs on Pavement loss of shape, unpublished technical report, New York.

Bell, F. (1999). Geological hazards: their assessment, avoidance and mitigation. **In:** *E & FN SPON*, Standard Publishers, London, Pp 648.

Bell, F. (2000). Engineering Geology: Concepts and Application.**In:** *E & FNSPON, Standard Publishers, London, Pp 243.*

Bowles, J.E. (1984). *Physical and Geotechnical properties of soils*. McGraw Hill, New York, 1089 pp.

Brigatti, M.F., Galan, E., and Theng, B.K.G. (2006).Structures and Mineralogy of Clay Minerals, Elsevier, Amsterdam, 925 PP.

Chen, F.H. (1988). Foundations on expansive soils. Elsevier Science Publishers, Amsterdam, 562pp

Chen,F.H.(1998),Foundations on expansive soils, Elsevier Science Pulishers B.V

Das, B.M. (2011). Principles of Foundation Engineering, 7th ed., CT: Global Engineering, Stamford, 794 pp

Ethiopian Building Code Standard (EBCS-3,1983).Code of Standards for design of steel structures. Ministry of Works and Urban Development, Addis Ababa, Ethiopia

Ethiopian Building Code Standard(EBCS-7, 1995).Foundations. Ministry of Urban and Development and Construction, Addis Ababa, Ethiopia

Ferguson DJ, Barnie TD, Pyle DM, Oppenheimer C, Yirgu G, Hamling IJ. 2009. Rift-related volcanism inAfar.Eos Trans. AGU 90(52), Fall Meet. Suppl., Abstr. T31B-1815

Gilloth,J.E (1962).Clay in Engineering Geology, Elsevier publishing Company,USA,567 pp

Gillot, P.Y. (1987). History Volcanic of rocks and their genesis: Arc Institute of complexes orogeny annular. *Documents of Travaux de l'Institut Geologique Albert de l'Apparent 11: 35-42.*

Craig, R.F (2004). *Craig's Soil Mechanics*, 7th ed. Spon Press, London and New York, 760PP.

Fell, R., MacGregor P., Stapledon D. and Bell G. (2005) *Geotechnical Engineering of Dams*, Tylor and Francis Group plc, London, UK.

Geological Society (1997). Tropical residual soils, the Geological society, Engineering group working party revised report, London.

(GSE) (Geological Survey of Ethiopia), (1996).*Explanation to the Geological Map of Ethiopia*, Institute of Geological Surveys, Addis Ababa, Ethiopia, 69 pp.

Haile SellasieGirmay and GetanehAssefa (1989). The Addis Ababa-Nazareth Volcanics: A Miocene-Pleistocene Volcanic Succession in Ethiopian Rift. *SINET, Ethiopian Journal of Science* **12** (1).

Holland, J.E. and Richards, J. (1982).Road Pavements on Expansive Clays.*Australian Road Research*.**12** (1) : 295pp

Holtz, W. and Gibbs, H. (1956).Engineering Properties of Expansive Clays, *American Society of Civil Engineers*.**121**: 641-677.

Holtz,R. (1973). The prediction and performance of structures on expansive soils.Unsaturated*SoilMechanics.New York: Academic Press, 729 pp.*

John, D. and Debora, J. (1992). *Expansive Soils-Problems and practice in foundation and pavement engineering*. John Wiley & Sons. Inc., New York, 790pp.

Kazmin, V. (1979).*Stratigraphy and Correlation of Volcanic Rocks in Ethiopia*.EIGS, Addis Ababa, Ethiopia.

KebedeTsehayu and TadesseH.mariam (1990).Engineering Geological Mapping of Addis Ababa,Ethiopian Geological Survey, Addis Ababa,Ethiopia,83-85

Lake Mariam Asfaw, (1986). Linear zone of subsidence in the Main Ethiopian Rifi near *Lake*Awasa.*Proceedings of the 5th international Cong., of Earthquake and* seismic design, London. pp. 761

Lyon Associates inc.,Laterite and lateritic soils and other problem soils of the Tropics,Vols.I and II,Baltimore,1971

Morin, W. (1971).Properties of African Tropical Black Soils.**In:** *Fifth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, eds:*-Luanda, Angola, pp. 51-65.

Morin, W. and Parry, W. (1971).Geotechnical Properties of Ethiopian Volcanic Soils, *Geotechnique*.**21**: 223-232.

Mohr,P.A.1962. In: The Geology of Ethiopia. *II Poligrafico, Asmara.*

Murray, H.H. (2007). *Applied Clay Mineralogy*. Elsevier scientific publishing company,
USA, 780 PP.

Murthy, V. (2009).*Principles and practices of soil mechanics and foundation engineering.*Marcel Dekker Inc., New York, 1029 pp.

Nelson, D. and Miller, J. (1992).*Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*. John Wiley & Sons, Inc, New York, 573pp.

Netterberg, F. (2001). Addis Ababa-Jimma road project preliminary report on cracking problem: Unpublished Report Ethiopian Roads Authority, Addis Ababa.

Pop,A.(1997).“Shrinkage-Swelling phenomena effects on buildings,” Engineering of Geology and the environment, vol.I, Balkema, Rotterdam,pp.327

Rao, D.V. (2007). Steps to Improve Roads on Black Cotton Soils, NMB Construction Information, India 780pp.

Ross, G. (1978). Relationships of Specific Surface area and clay content to shrink-swell potential of soils having different clay mineralogical compositions. *Canadian journal of soil science*.**58**:159-166.

Samuel Kinde (1998).Proposed Considerations for Revision of EBCS-8:1995 for Conservative Seismic Zoning and Stringent Requirements for TorsionallyIrregural Buildings

SisayAlemayehu. (2004). Assessment of Damages of Buildings Constructed in Expansive Soil Area of Addis Ababa.Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 78pp.

Skempton, A.W. (1984). Advances in Geotechnical Engineering.**In:** Technology & Engineering - 281 pages

Snethen,D.R.(1975).A Review of Engineering Experiences with Expansive soils in Highway subgrades in the united states Army Engineer Waterways Experiment station, Interim Report, Federal Highway Administration office of Research And Development Washington D.C.20590.

TamiruAlemayehu, TenalemAyenew, DagnachewLegese (2006).Ground Water Vulnerability Mapping of the Addis Ababa water supply Aquifers. Addis Ababa University, Department of geology and geophysics (AAU) and Addis ababa Water and sewerage Authority (AAWSA),Addis Ababa,Ethiopia,79-81pp

Tesfaye Chernet, (1988).*Hydrogeology of Ethiopia and Water Resources Development*.Ethiopian Institute of Geological Survey, Addis Ababa.

The Clay Bowl Effect: Foundation technology your guide to what goes on under your feet peak, structuralhttp://www.lungusa.org/site/c.dvLUK9O0E/b.4061173/apps/s/content.asp?cthttp://www.basementsystems.com/learning_center/basement/clay_bowl_effect.php accessed on 23-May -2015

Thomas, P., Baker, J.C. and Zelazny, L. (2000). An Expansive Soil Index for Predicting Shrink-Swell potential, *Soil Science Society of America*. **64**: 268-274.

Ulusay R. (2002). *A simple test and predictive models for assessing swell potential of Ankara (Turkey) Clay*. Elsevier scientific publishing company, Amsterdam, 712pp.

Van Der Merwe, D. (1964). The prediction of heave from the plasticity index and percentage clay fraction of soil.*South African Institute of Civil Engineers*.**6:** 103-107.

John, D. and Debora, J. (1992). *Expansive Soils-Problems and practice in foundation and pavement engineering*. John Wiley & Sons. Inc., New York, 790pp.

Jones, J. and Holtz, W.G. (1973).Expansive Soils- The hidden disaster Civil Engineering.American Society of Civil Engineers (*ASCE)*.**43**: 49-51.

Yong, R. and Warkentin, B.P. (1975).*Soil properties and behavior*. Elsevier Scientific Publishing Company, Amsterdam, 890pp.

Zanettin, B, B. and Justin, V.E. (1974).*The Volcanic of Western Afar and Ethiopian Rift Margins*. Padova, Italy, 480pp

THE RESEARCH QUESTIONNAIRE FOR CONTRACTOR AND CONSULTANT

Impact of expandable soil on foundation of building structures: The case of condominium houses in Addis Ababa

Instruction

- Read the questions very carefully and answer them by circling or write your answer with the space provided.
- Don't write your name

Contractor (Site Engineer, Forman)……………………………………….

Consultant (Resident Engineers and supervisor)…………………………..

Condominium Site ……………………………………….

Sub city…………………………………………………..

I. Phases of construction

1. How do you construct condominium houses on expansive soil? (The process of construction)

1.1. Backfilling history and whether it is dry or wet?

………………………………………………………………………………………………
………………………………………………………………………………………………

1.2. Compaction history?

………………………………………………………………………………………………
………………………………………………………………………………………………

2. What did you observe before and after the construction?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

II. Water information and moisture movement

3. How is water from the roof discharged?

……………………………………………………………………………………………………
………………………………………………………………………………………………

4. Is there any history of leakage water or sewer system?

A. yes B. No

C. If yes, indicate point/location and the source of the leak

……………………………………………………………………………………………………
……………………………………………………………………………………………….

5. Is the area subject to flooding?

A. Yes B. No

III. Back ground of the condominium houses

6. Is there any detail site investigation done in this condominium houses construction area before the construction is takes place?

A. yes B. No

7. If your answer is yes for question No.6 could you mention type of detail of the investigation in brief?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

8. Was initial architectural design carried out?

A. yes C. partially

B. No D. If yes;

Who conducted it?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

What were his educational level and his experience?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

9. Were properly geotechnical test carried out?

A. yes C. Partially

B. No

If yes, who conducted them?

……………………………………………………………………………………………………

What were his educational level and his experience?

……………………………………………………………………………………………………

10. Can the geotechnical data be retrieved?

A. yes

B. No

C. If yes, how?

……………………………………………………………………………………………………

11. Was structural analysis carried out?

A. yes

B. No

C. partially

If yes, who conducted them?

…………………………………………………………………………………………………
……………………………………………………………………………………………..

What were his educational level and his experience?

…………………………………………………………………………………………………
……………………………………………………………………………………………..

12. Is there any subsequent conversion or adaptation to the initial structure?

A. yes

B. No

C. If yes, mention the additions and modifications

…………………………………………………………………………………………………
………………………………………………………………...

13. How long have you worked here?

…………………………………………………………………………………………………

14. What is a standard of workmanship?

A. very good

B. Good

C. Fair

D. Poor

16. Foundation type and footing system and materials

………………………………………………………………………………………………………
………………………………………………………………………………………………………

16. Foundation depth x breadth

………………………………………………………………………………………………………

17. Walls type and materials

………………………………………………………………………………………………………

18. Roof material

………………………………………………………………………………………………………
………………………………………………………………………………………………………

IV.Expansive soil and its causes to the damage of condominium houses

19. Do you believe that expansive soil on condominium houses is a serious problem? (Please circle)

A. yes B. No

20. If yes for question No.19 how serious problem is? (The extent of serious)

………………………………………………………………………………………………………
………………………………………………………………………………………………………
……………………………………………………………………………………

21. Have you seen damage of condominium houses constructed on expansive soil?

A. yes B. No

22. If yes for question No.21 where are there site?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

23. Especially which part of condominium houses are damaged?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

24. Can you mention damage of condominium houses in detail?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………………………………………………………………………

V.Remedial measures

25. Have you given special attention for expansive soil rather than others?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

26. Do you use remedial measures for already damaged area of condominium houses?

A. yes B. No

27. If your answer is yes for question No.26 could you mention the type of remedial action which is used for damaged areas of condominium houses?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

28. What measures should have been taken to treat the expansive soil?

……
……

29. Which type of soil treatment takes places on expansive soil to construct condominium house?

……
……

30. Which foundation type is better for you to minimize damage of condominium houses constructed on expansive soil?

……
……

31. Is there any especial solutions forwarded by Addis Ababa housing construction project office to minimize the damage?

……
……

VI. Perception

32. What is your worries regarding condominium house constructed on expansive soil?

……
……

33. What are the attitudes of those people suffered by damaged condominium house?

……
……

34. What will be your priority if you get a chance to construct this condominium site again?

……
……

35. Do you support condominium programe to takes place in Addis Ababa? (Please circle)

A. yes B. No

36. If your Answer is yes for question no.35 what would be your reason?

……
……

37. If your answer is no for question no.35 what would be your reason?

……
………………………………………………………………………………………………………

RESEARCH QUESTIONNAIRE FOR THE OWNER OF THE CONDOMINIUM HOUSE

Instruction

- Read the questions very carefully and answer them by circling or write your answer with the space provided.

- Don't write your name

Condominium site………………………………..

Block No……………………………………

Sub-city……………………………………………

I. Block and condominium report

1. Block No………………………………………………
2. Location…………………………………………………
3. Site condition…………………………………………..
4. Soil type………………………………………………..
5. Age of condominium………………………………………
6. Construction date……………………………………………
7. In which floor do you live? ....

II. Construction details/Materials

1. When did you receive your condominium house?

A. Before ten years

B. Before seven years

C. Before three years ago

D. Renter

2. Which part of your house shows damage or failure?

A. Floor

B. Wall

C. Other

3. What are the main problems of your house?

……
……
………………………………………………………………………………………………………..

4. Is there defect of omission or possible absence of critical component?

A. yes

B. No

C. If yes, what type of omission?

……

5. Is there any typical movement?

A. yes

B. No

C. If yes, indicate the location

……

6. Brief description of the condition of the structure e.g cracks, heaves, bows, sags, leans etc

……
………………………………………………………………………………………………………..

7. Are there signs of serious cracks?

A. yes

B. No

C. If yes,

- Indicate crack location and pattern?

……

8. Estimate the crack size?

……
………………………………………………………………………………………………

9. Point out the probable cause of cracks e.g soil heaving, soil shrinkage, expansion of materials?

……
………………………………………………………………………………………………

10. Are the Doors and the windows sticking?

....
....

11. Is there any appreciable gap between the top of the door and doorframe header?

……
……………………………………………………………………………………………….

12. Is the structure will serving its purpose?

....

....

13. Is the condominium houses about to collapse?

....

....

14. Is there any sign of standard and adequacy of maintenance that has been carried out?

…………………………………………………………………………………………………

………………………………………………………………………………………….

15. How were different phases of construction performed?

15.1 Backfilling history and whether was it dry or wet?

…………………………………………………………………………………………………

………………………………………………………………………………………….

15.2 Compaction history?

…………………………………………………………………………………………………

…………………………………………………………………………………………

16. Are remedial measures necessary?

A. yes

B. No

C. If yes, indicates the parts calling remedial measure?

…………………………………………………………………………………………………

…………………………………………………………………………………………

17. Is there any previous foundation repair or underpinning?

A.yes

B.No

C.If yes

16.1 What type of repairs and how many times?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………

16.2 who carried out the repairs?

…………………………………………………………………………………………………
…………………………………………………………………………………………..

16.3 What were his educational level and his experience?

…………………………………………………………………………………………………
………………………………………………………………………………………………..

17. How is water from the roof discharged?

…………………………………………………………………………………………………
…………………………………………………………………………………………

18. Is there any history of leakage water or sewer system?

A. yes

B. No

C. If yes, indicate point/location and the source of the leak

…………………………………………………………………………………………………
……………………………………………………………

19. Is the area is subject to flooding?

A. yes

B. No

20. What are the biggest advantages of condominium programme here in this site?

A. it reduce house rent

B. facilitate education

C. It facilitate health center

D. It facilitate infrastructure

E. All of the above

F. others

21. Which condominium site is well constructed in Addis Ababa for you? Why?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

22. Do you believe that damage of condominium houses in this site is serious problem?

A. Yes B. No

23. If your answer is yes for question No.25. How it can be serious?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

24. What is your worries regarding your house and your condominium site?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

25. What are the situations of those around you who are having condominium house?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

26. Are you support condominium houses programe to takes place in your site? (Please circle)

A. Yes B. No

27. If your Answer is yes for question No.26.What would be your reason?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

28. If your answer is no for question No.26.What would be your reason?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………….

Appendix 1: KoyefecheSite, the abovephotos show the columns are notconnected with the foundation reinforcement and shifting of eccentricity

Appendix 2:Koyefeche, these photos show Shifting of eccentricity

Appendix 3: Koyefeche, the left side of the photo shows the column is not connected with the foundation reinforcement and the right side of the photo shows shifting of eccentricity

Appendix 4: Bole Arabsa 5, this figure shows after a certain depth the picture seems stone however, a manner touch disintegrate in to small particles.

Appendix 5: These precast were broken down on the spot of dropping from the car when I was conducting field observation (Bole Arabsa 3)

Appendix 6: Differential settlement problem and settlement of masonry wall below the grade beam

Appendix 7: Currently, the flat areas are highly affected by flooding and emerging up of small streams, thus affecting Koyefeche Construction sites

Appendix 8: koyefeche project 12**(G+7)** and selected for isolated footing

Appendix 9: Bole Arabsa 5 (G+7) and Mat Foundation

Appendix 10: Bole Arabsa 3: Excavating pile of soil for backfill and the practice is applicable for the purpose of cost cutting

Appendix 11:BoleArabsa 3 boulders

Appendix 12: Bole Arabsa 3

Appendix 13:Severe diagonal fence wall crackingin Bole area due to gardenwatering

Appendix 14:Lamberet-Transport route damage due to expansive soil and Compaction Problem


Appendix 15: Semit G+4: Failure of building which was being constructed on expansive soil

Appendix 16: Semit G+4: Collapsed of unfinished building

Appendix 17: Yeka Ayat No.2 Block 304 HNo.1 Sewerage Pipe Broken and the whole sewerage drops in to the ground floors.Broken sewerage pipe may be occurred due to soil movement.

Appendix 18: Geographical description of soil sample areas

No	Sites	Location	Colors	Depth	Northing	Easting	Elevation
1	**Bole Arabsa 5**	Sample No.1	Black	2.5m	0487092	0990627	2300m
2		Sample No.2	greyish	2m	0497023	0990895	2302m
3		Sample No.3	Black	1.5m	0486941	0990817	2296m
4		Sample No.4	Black	2m	0486958	0990756	2297m
5		Sample No.5	greyish	1.5m	0487017	0990827	2295m
6	**Bole Arabsa 6**	Sample No.1	greyish	2.5m	0487502	0990422	2306m
7		Sample No.2	Black	1.5m	0487632	0990410	2305m
8		Sample No.3	Black	2m	0487611	0990518	2301m
9		Sample No.4	greyish	2.5m	0487642	0990529	2298m
10	**Koyefeche project 12**	Sample No.1	Black	2m	0481348	0985200	2207m
11		Sample No.2	Black	1.5m	0481286	0985296	2202m
12		Sample No.3	Black	2.5m	0480863	0984940	2194m
13	**Koyefeche project 16**	Sample No.1	Black	2.5m	0480436	0985522	2212m
14		Sample No.2	Black	2m	0480892	0985457	2213m
15		Sample No.3	Black	1.5m	0480406	0985462	2200m
16	**Koyefeche project 17**	Sample No.1	Black	2.5	0481454	0984498	2198m
17		Sample No.2	Black	2m	0481708	0984475	2211m
18		Sample No.3	Black	1.5m	0481770	0984539	2196m

Candidates Declaration

I here by declare that the work which is being presented in this thesis entitles: "**Impact of expandable soil on foundation of building structures: The case of condominium houses in Addis Ababa"** This is original work of my own has not been presented as a thesis for a degree in any other university. All sources of materials used for this have also been duly acknowledged.

Date of Defense: October 10, 2016

_____________ _____________

Dejenie Abere Date

(Candidate)

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

_____________ _____________

Dr.Trufat Hailemariam Date

(Thesis Advisor)